1. AMPLITUDE MODULATION

Introduction to communication system:

Communication:

Communication is defined as the basic process of exchanging information.

→ An information signal is transmitted from transmitter to receiver.

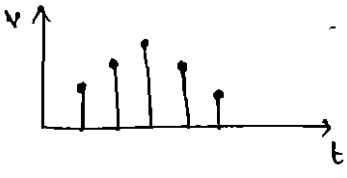
→ Based on the nature of signal transmitted, communication system is of 2 types. ① Analog communication system.
② Digital communication system.

① **Analog communication system:** The message signal used in this system is analog in nature. A signal whose amplitude varies continuously with respect to time period is analog signal.

Eg: sine wave, cos wave,

② **Digital communication system:** The message signal to be transmitted is digital in nature. A signal in which the sequence of numbers represent the amplitude at any instant of time is called digital signal. It is discrete in nature.

Eg:



→ Digital communication systems are preferred over analog communication systems.

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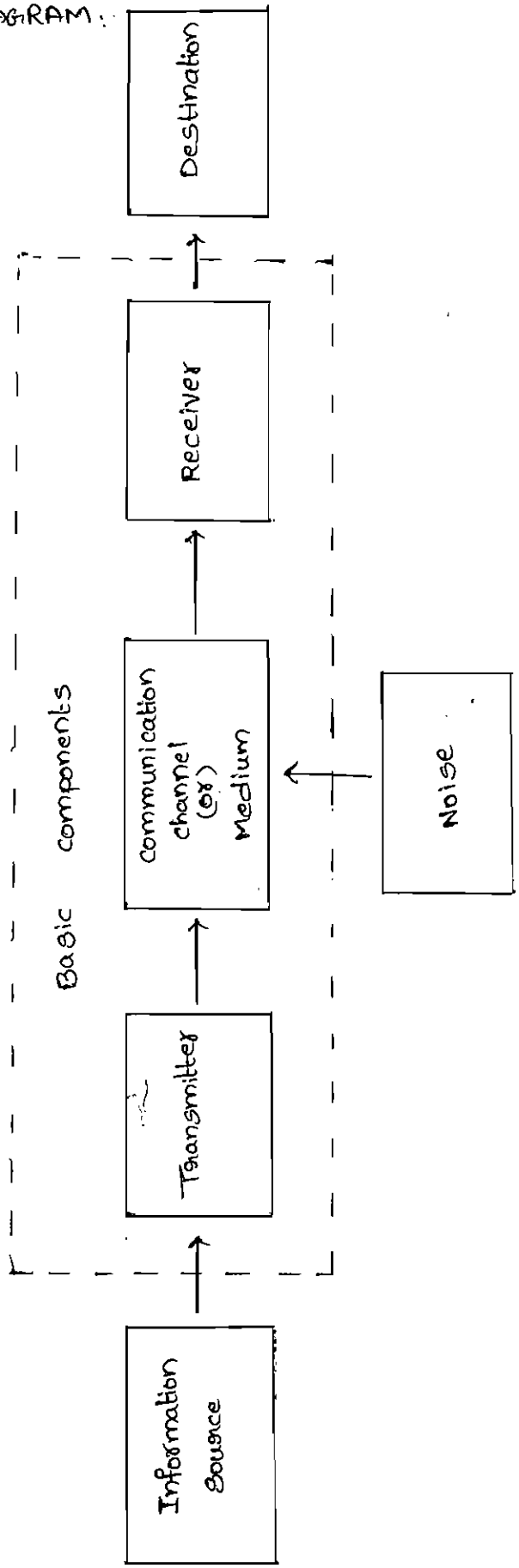
Basic elements (or) components of a communication system:

BLOCK DIAGRAM:



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The basic components of communication system are transmitter, a communication channel or medium and a receiver.

① Information :

The information source contains message that is to be transmitted. The two main sources of information are the ideas emanating from the human brain and changes in any physical environment. The amount of information contained in any given message is measured in bits or dits.

② Transmitter :

The transmitter is a collection of electronic circuits designed to convert the information into a signal suitable for transmission over a given communication medium.

Some message signals that comes from information source is non-electrical and it is not suitable for transmission. Inorder to transmit the signal, it should be converted into electrical. The built-in circuitry such as decoders, encoders, transducers etc. in the transmission makes incoming information suitable for transmission and subsequent reception.

③ Communication channel :

The communication channel is the medium by which the electronic signal is transmitted from one place to another. Depending on the type of medium, the communication system can be classified as

- coire communication (or) Line communication
- coireless (or) Radio communication.

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④ Noise:

Noise is an unwanted random signal which interfere with the message signal launched by the transmitter. This problem is particularly common in broadcasting, where two or more signals may be picked up at the same time by receiver which inturn will produce different message.

Noise in communication system can be classified as internal noise and external noise. Noise generated by components with in a communication system such as resistors, diode and transistors are referred to as internal noise. The external noise results from sources outside a communication system such as atmospheric and man-made.

⑤ Receiver:

A receiver is a collection of electronic circuits, designed to convert the signal back to the original information. It consists of amplifier, decoder, mixer, oscillator, transducer and so on. The output transducer converts the electrical message signal into its original form.

BASE BAND SIGNAL:

The original message signal whether it may be analog or digital is called a base band signal.

→ The frequency and amplitude of a baseband signal is low and hence it can not travel longer distances. These signals should be modulated for travelling long distance.

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MODULATION:

Def: The process of changing characteristics (amplitude, frequency, phase) of the carrier (high frequency) signal with respect to instantaneous amplitude values of the modulating (message or low frequency) signal is known as modulation.

Need for modulation:

Modulation technique is used for the communication of base band signal. The need for modulation (or) advantages of modulation is given below:

① Reduces the height of antenna.
② Avoids mixing of signal.
③ Increases the range of communication
④ Allows multiplexing of signals
⑤ Allows adjustments (or) changes in bandwidth.
⑥ Improves quality of reception.

① Reduces the height of antenna:

The height of antenna required for transmission and reception of radiowaves in radio transmission is a function of wavelength of frequency used. The minimum height of antenna required for perfect (i.e., 100 %) modulation should be

$$h = \lambda/4$$

and $\lambda = \frac{c}{f}$ where 'c' is the velocity of light and f is the frequency.

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The above equation said that, at low frequencies, wavelength of the signal is high and the height of antenna also be high.

For example, consider a signal with frequency $f = 15kHz$

$$\text{height of antenna } h = \frac{\lambda}{4} = \frac{c}{f \times 4} = \frac{3 \times 10^8}{15k \times 4}$$

$$= \frac{3 \times 10^8}{15 \times 10^3 \times 4}$$

$$= 5000 \text{ meters}.$$

$\Rightarrow$ Antenna height should be 5 km.

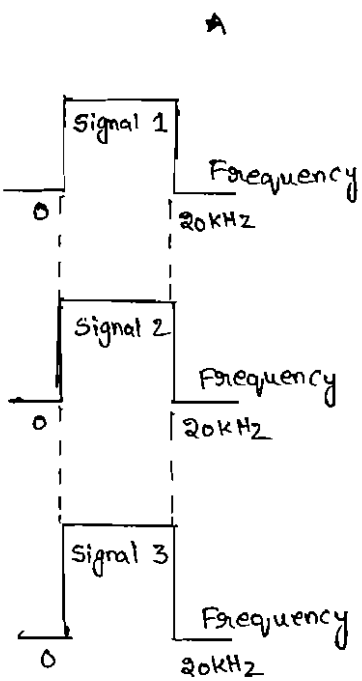
Now consider a signal of frequency $f = 1MHz$

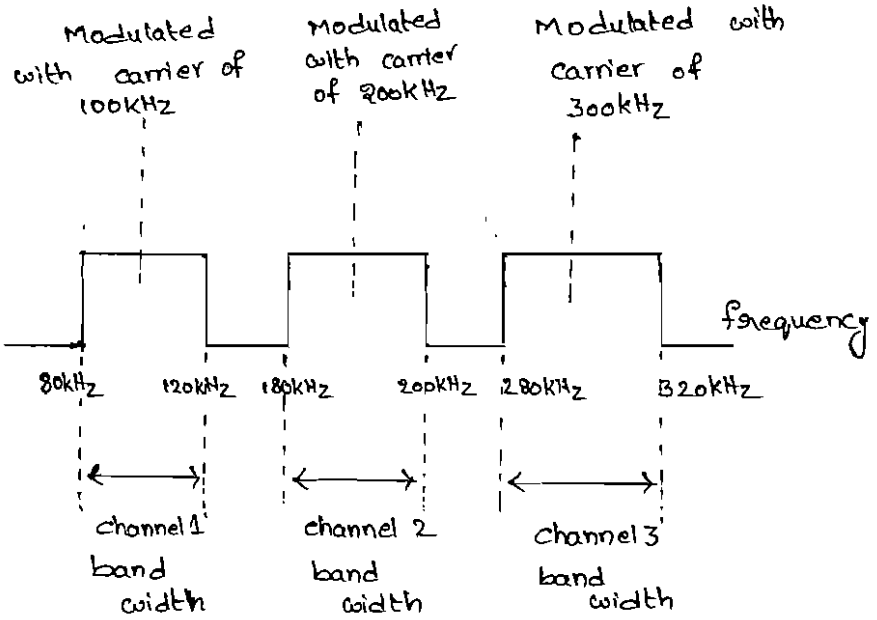
$$\text{height of antenna } h = \frac{\lambda}{4} = \frac{c}{f \times 4} = \frac{3 \times 10^8}{1M \times 4} = \frac{3 \times 10^8}{1 \times 10^6 \times 4}$$

$$= \frac{300}{4} = 75 \text{ meters}.$$

$\Rightarrow$ Antenna height is 75 meters which is practically possible and can be installed.

(2) Avoids mixing of signals:





All sound signals are concentrated within the range from 20 Hz to 20kHz. There is a problem of mixing of signals with same frequency range during transmission. Then it is difficult to separate at the receiver end. This problem can be overcome by modulating carrier signal by different carrier frequencies. Once the signals have been transmitted, a tuned circuit at the receiver end selects the six different signals it is tuned for, as shown in the above figure.

③ Increases the range of communication:

At low frequencies radiation is poor and signal gets highly attenuated. Therefore baseband signals cannot be transmitted directly over long distance. Modulation effectively increases the frequency of the signal to be radiated and thus increases the distance over which signals can be transmitted faithfully.

④ Allows multiplexing of signals:

Multiplexing means transmission of two or more signals simultaneously over the same channel. The different signals from different stations can be separated in the receiver since the carrier frequencies for these signals are different. It is commonly known as tuning the receiver to the desired station. By tuning process, the desired signal is selected and at the same time, other unwanted signals are rejected.

⑤ Allows adjustments in the bandwidth:

Bandwidth of a modulated signal may be made smaller or larger than the original signal. Signal to noise ratio in the receiver which is a function of the signal bandwidth can thus be improved by proper control of the bandwidth at the

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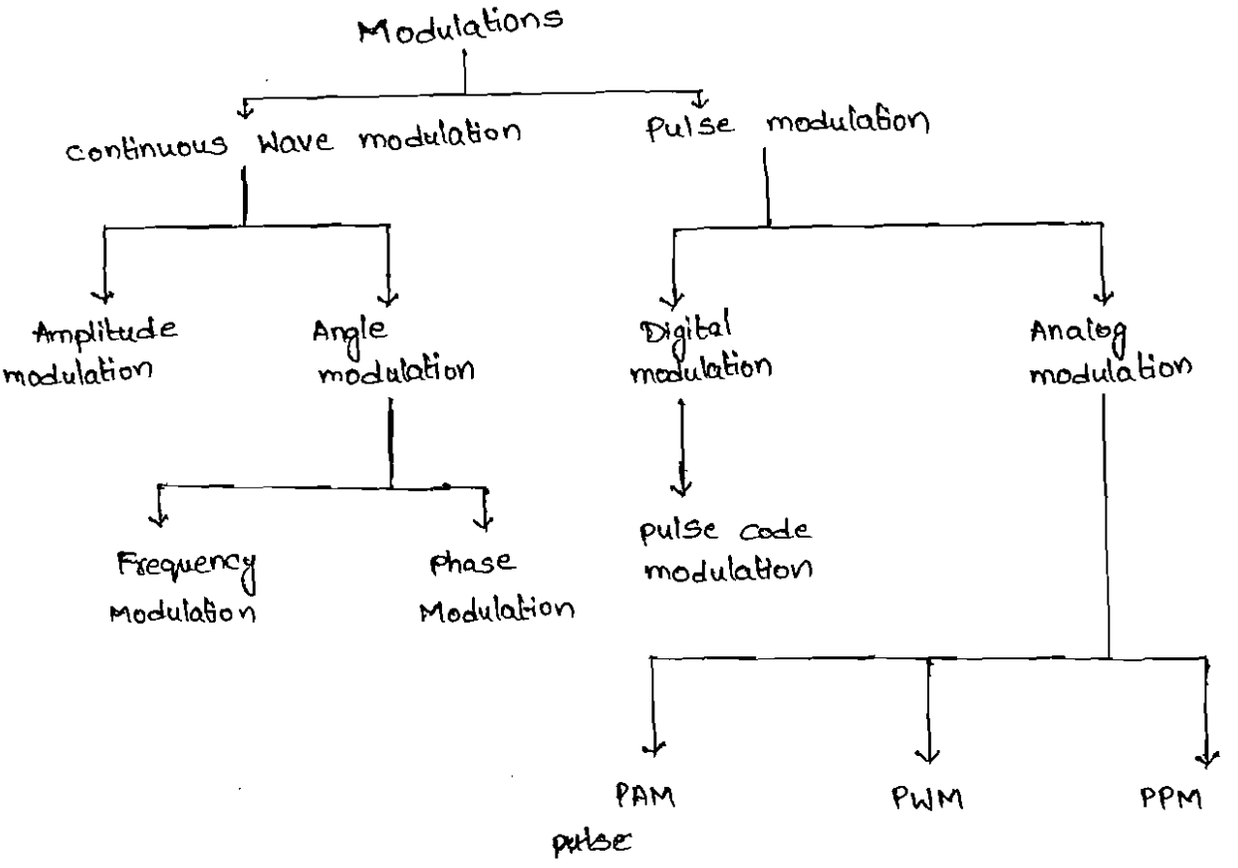
modulating stage.

⑥ Improves quality of reception :

The signal communication using modulation techniques such as frequency modulation, pulse code modulation reduce the effect of noise to great extent. Reduction in noise improves the quality of reception.

Types of modulation :



PAM - pulse amplitude modulation

PWM - Pulse width modulation

PPM - pulse position modulation

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MULTIPLEXING :

Def: Multiplexing is defined as a process of simultaneous transmissio of several messages over a single channel in a way that they do not interfere with each other.

→ At the receiving end, individual signals can be extracted from the multiplexed signal by demultiplexing process.

→ Demultiplexing means one-to-many.

→ Multiplexing means many-to-one.

Applications :

Multiplexing finds use in most modern day telecommunication processes like i) telephony

ii) satellite communication

iii) wireless communication

iv) telemetry ...etc.

These are mainly two types of multiplexing methods in use.

1) Frequency division multiplexing.

2) Time division multiplexing.

1) Frequency Division MULTIPLEXING :

In frequency division multiplexing (FDM), the total channe bandwidth available to the system is divided into smaller non-overlapping frequency bands (sub-bands), which enables the receiver to separate them and recover the individual messages.

The block diagram of a typical FDM system is shown in figure. Consider three message signals $m_1(t)$, $m_2(t)$, $m_3(t)$.

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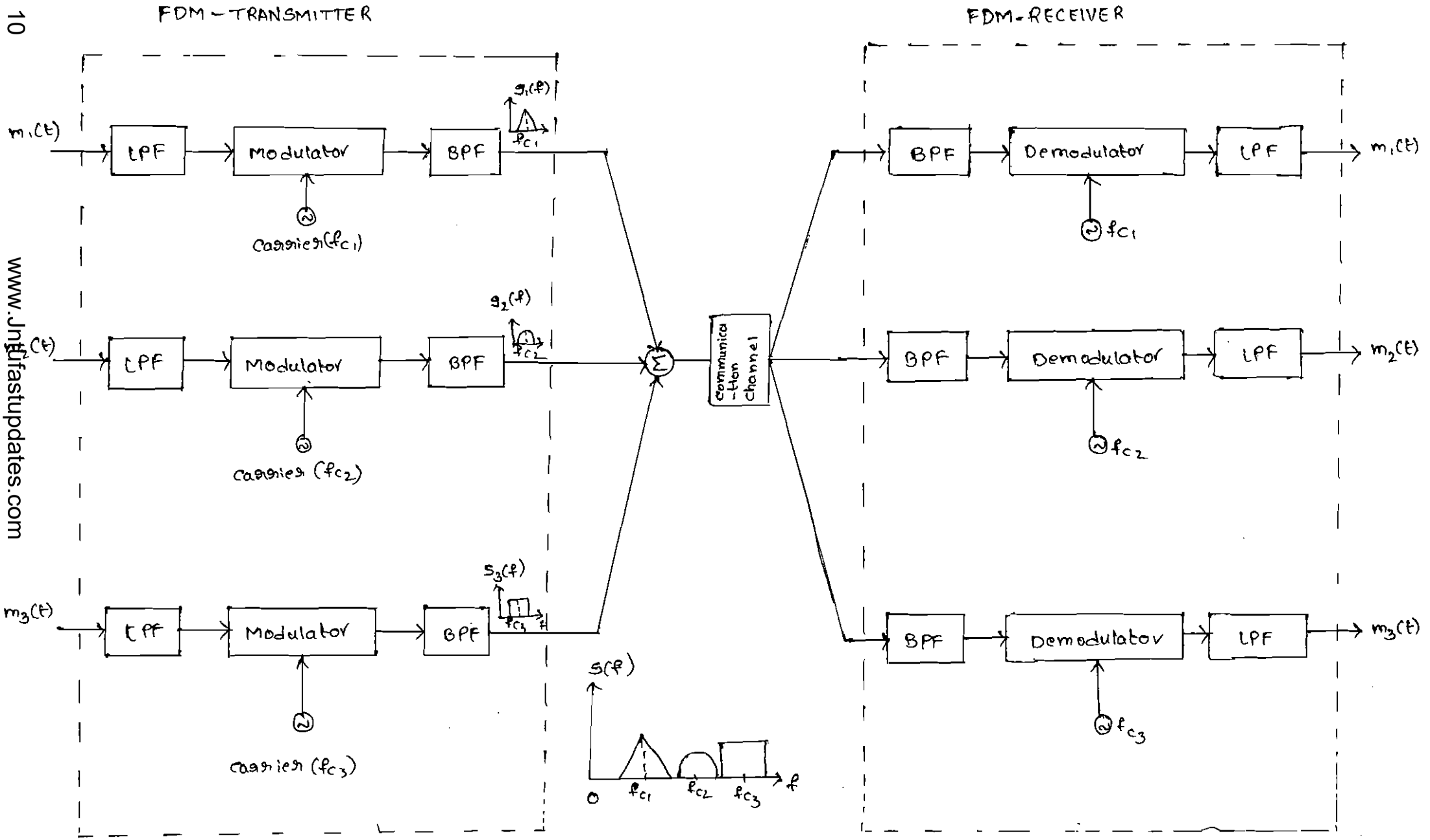

The Low Pass Filter (LPF) at the transmitter section of FDM system, removes high frequency components of message signal that disturbs the other message signals that share the channel. These filtered signals modulate the carriers having the frequencies $f_{c_1}, f_{c_2}, f_{c_3}$ so that the resulting modulated waves do not have overlapping spectra.

The band pass filters (BPF) after the modulators are used to restrict the band of each modulated wave to prescribed range. All these signals are now combined to produce a composite signal $s(t)$ which is then transmitted over the channel.

In the receiving end, suitable BPF's, tuned to the carrier frequencies are then employed to recover each of the modulated carriers carrying the individual signals. Each modulated signal is again passed through a demodulator to get back the original message.

→ In an FDM system, the bandwidth allocated to each sub-band is slightly larger than the bandwidth needed by each message. This extra bandwidth, is called a guard band.

Channel bandwidth of FDM system:

If 'n' message signals, each having a bandwidth equal to 'W' Hertz, then the minimum bandwidth of the channel should be greater than nW Hertz. i.e.,

$$\text{Channel B.W of FDM} \geq nW \text{ Hertz}$$

Where 'n' indicates the number of messages to be multiplexed.

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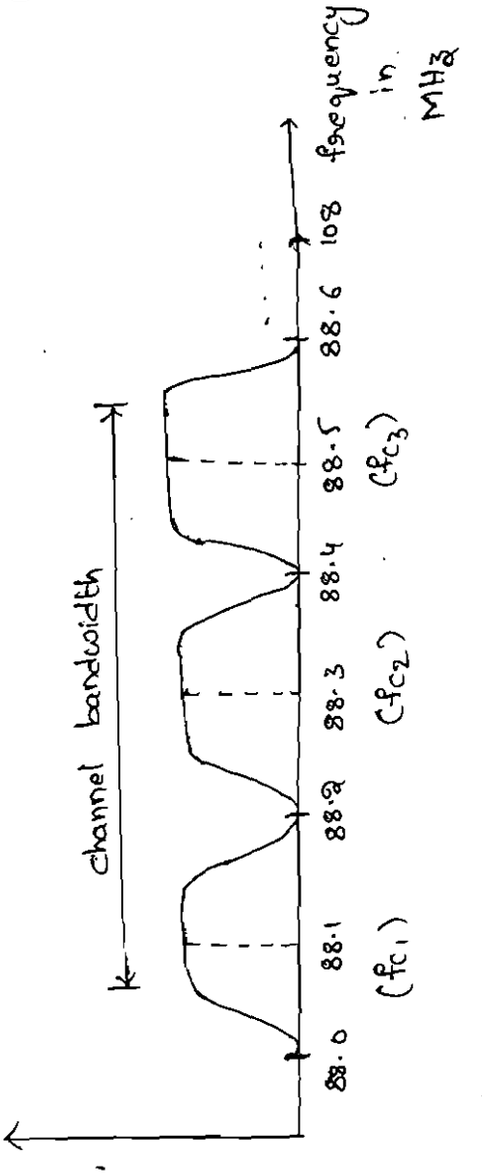
Applications of FDM:

FDM is used in telephone-system, telemetry, commercial broadcast, television and communication networks. commercial FDM broadcasting stations uses frequency band from 88MHz to 108 MHz. This 88-108 MHz frequency band is divided into sub-bands of bandwidth 200kHz. The FM stations are identified by the center-frequency within their channel (e.g., 88.1 MHz, 88.3 MHz, ... 107.9). This system can provide radio listeners with their choice of upto 100 different radio stations.



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Amplitude Modulation

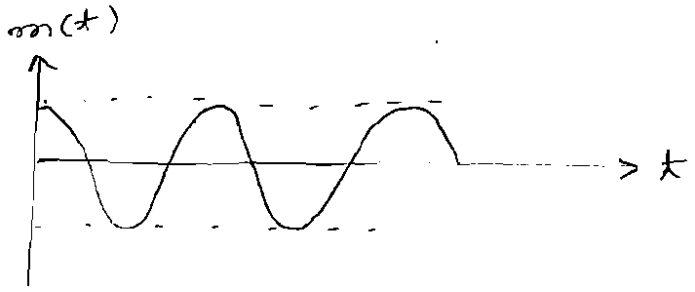
→ In amplitude modulation, the amplitude of a carrier signal is varied in accordance with the instantaneous values of modulating signal.

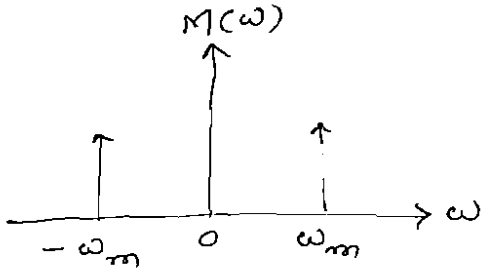
single tone modulation:

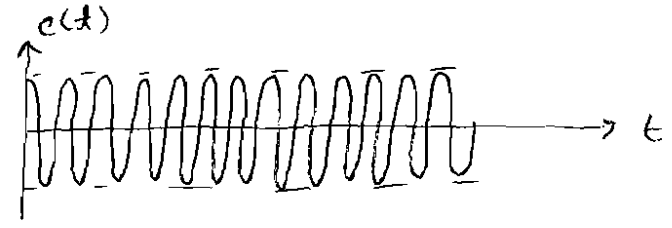
Let us consider the modulating voltage be

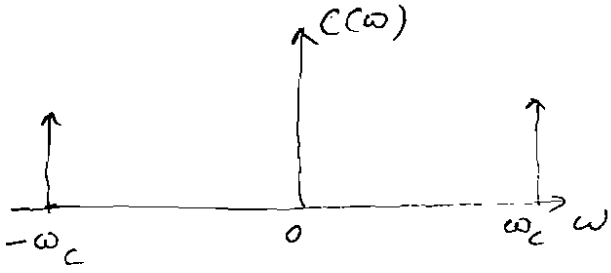
$$m(t) = v_m(t) = V_m \cos \omega_m t$$ and high frequency carrier signal be

$$c(t) = v_c(t) = V_c \cos \omega_c t$$









→ from the definition of amplitude modulation, the amplitude of the carrier is changed according to the instantaneous values of amplitude of message/modulating signal

$$\therefore V_{Am} = V_c + m(t)$$

$$= V_c + V_m \cos \omega_m t$$

$$= V_c \left[1 + \frac{V_m}{V_c} \cos \omega_m t\right]$$

$$= V_c [1 + \mu \cos \omega_m t]$$

$$= V_c [1 + k_a m(t)]$$

where $k_a = \frac{1}{V_c}$

where $\frac{V_m}{V_c} = \mu$ called modulation index or modulation depth of modulation or modulation factor

$K_a = \frac{1}{V_c}$ = amplitude sensitivity

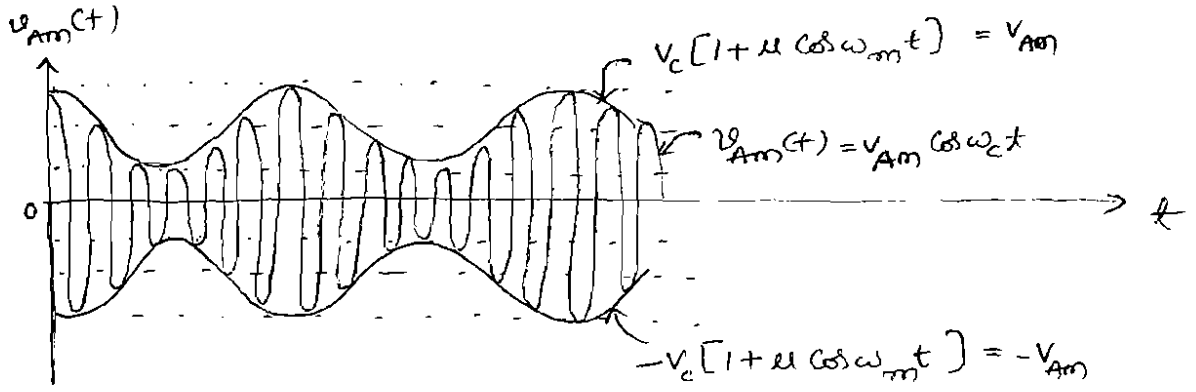
∴ The instantaneous amplitude of modulated signal is given by

$$v_{Am}(t) = V_{Am} \cos \omega_c t$$

$$= V_c [1 + m \cos \omega_m t] \cos \omega_c t$$

(or)

$$= V_c [1 + K_a m(t)] \cos \omega_c t$$



Frequency domain description:

$$v_{Am}(t) = V_c [1 + m \cos \omega_m t] \cos \omega_c t$$

$$= V_c \cos \omega_c t + m V_c \cos \omega_m t \cos \omega_c t \quad \times \frac{2}{2}$$

$$= V_c \cos \omega_c t + \frac{m V_c}{2} \, 2 \cos \omega_m t \cos \omega_c t$$

$$= V_c \cos \omega_c t + \frac{m V_c}{2} [\cos(\omega_c + \omega_m)t + \cos(\omega_c - \omega_m)t]$$

$$= V_c \cos \omega_c t + \frac{m V_c}{2} \cos(\omega_c + \omega_m)t + \frac{m V_c}{2} \cos(\omega_c - \omega_m)t$$

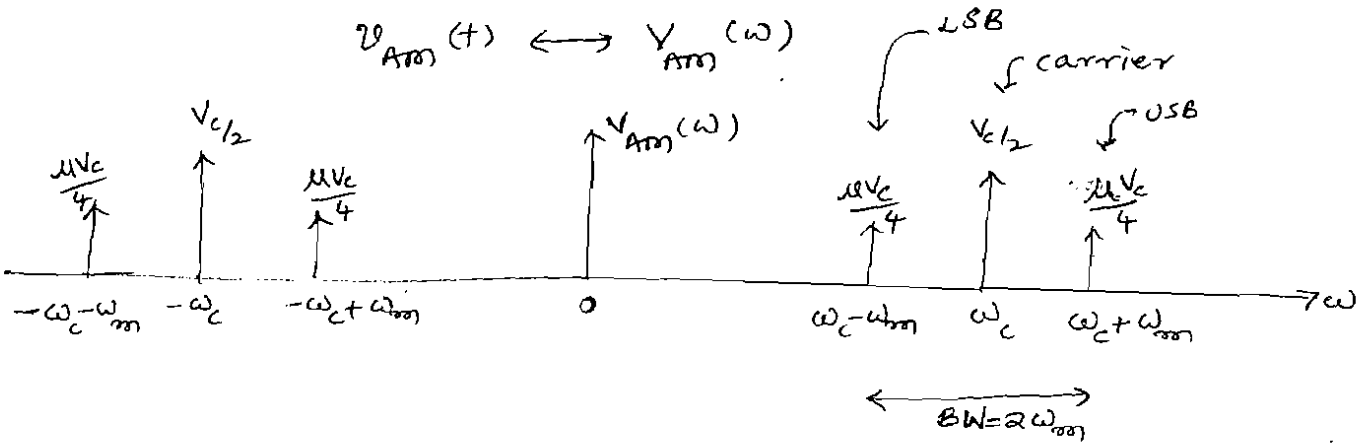
// $2 \cos A \cos B = \cos(A+B) + \cos(A-B)$

$x(t) \longleftrightarrow X(\omega)$

$x(t) \cos \omega_0 t \longleftrightarrow \frac{1}{2}[X(\omega+\omega_0) + X(\omega-\omega_0)]$

$x(t)\left[\frac{e^{j\omega_0 t} + e^{-j\omega_0 t}}{2}\right]$

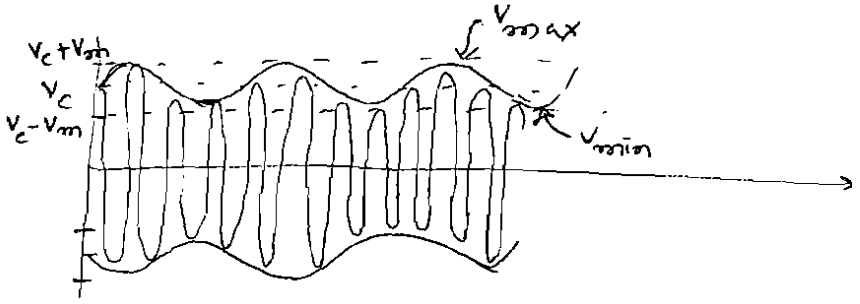
$\frac{1}{2}[x(t) e^{j\omega_0 t} + x(t) e^{-j\omega_0 t}]$ $\longleftrightarrow \frac{1}{2}[X(\omega+\omega_0) + X(\omega-\omega_0)]$



// multiplication with cos signal shifts the spectrum of the signal to both sides and makes magnitude half

$$BW = \omega_c + \omega_m - (\omega_c - \omega_m)$$
$$= \omega_c + \omega_m - \omega_c + \omega_m = 2\omega_m$$

Calculation of modulation index:



$$\mu = \frac{V_m}{V_c}$$

$$V_{max} - V_{min} = V_c + V_m - (V_c - V_m) = 2V_m$$

$$V_m = \frac{V_{max} - V_{min}}{2}$$

$$V_c = V_{max} - V_m$$
$$= V_{max} - \left[\frac{V_{max} - V_{min}}{2}\right] = \frac{2V_{max} - V_{max} + V_{min}}{2}$$
$$= \frac{V_{max} + V_{min}}{2}$$

$$\therefore \mu = \frac{V_m}{V_c} = \frac{V_{max} - V_{min}}{V_{max} + V_{min}}$$

$$\mu = \frac{\text{amplitude change of carrier}}{\text{Normal carrier wave}} = \frac{V_c(max) - V_c}{V_c}$$

Alternate: from $v_{AM}(t)$ eqn

$V_{max} = V_c[1+\mu]$

$V_{min} = V_c[1-\mu]$

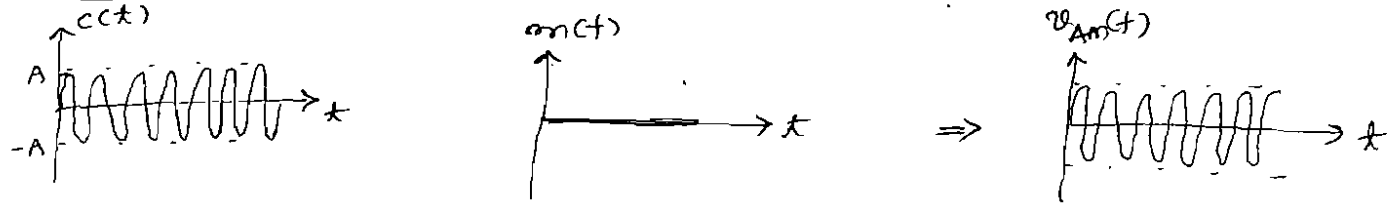
$V_{max} = V_c + V_c\mu \rightarrow ①$

$V_{min} = V_c - V_c\mu \rightarrow ②$

Solving eqns ① & ②

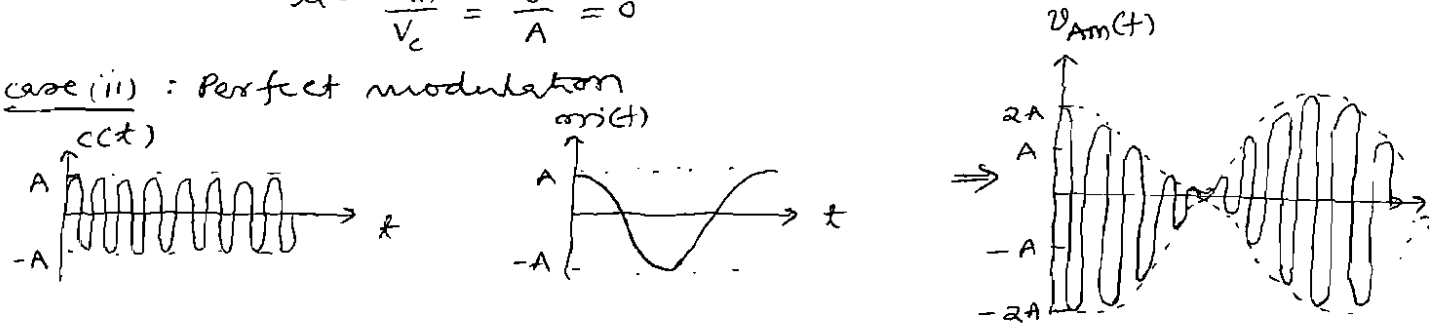
$\mu = \frac{V_{max} - V_{min}}{V_{max} + V_{min}}$

Case(i) : No modulation



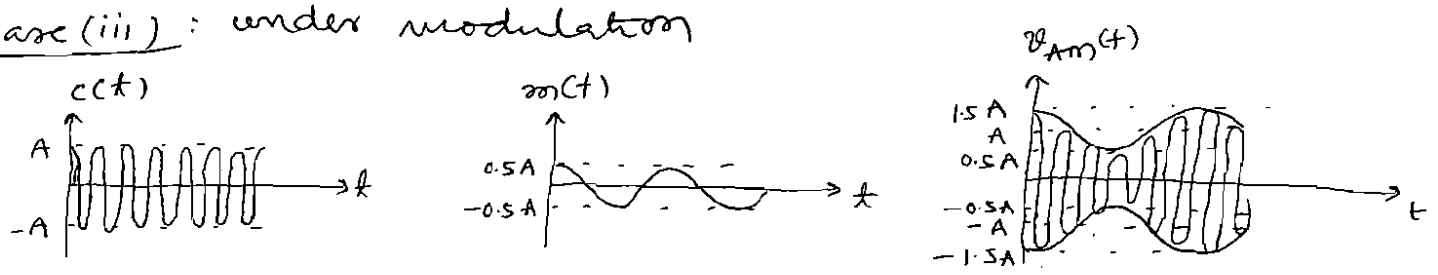
$$\mu = \frac{V_m}{V_c} = \frac{0}{A} = 0$$

Case(ii) : Perfect modulation



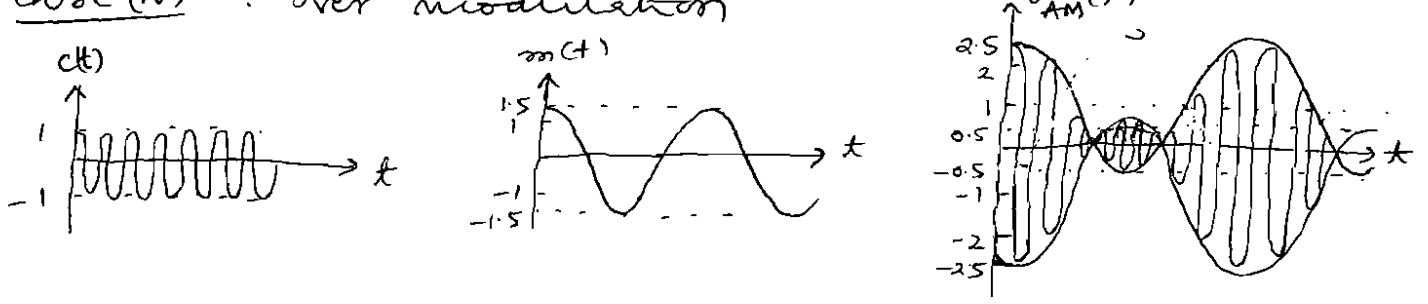
$$\mu = \frac{V_m}{V_c} = \frac{A}{A} = 1 \cong 100\%. \qquad \cong \frac{V_{max} - V_{min}}{V_{max} + V_{min}} = \frac{2A-0}{2A+0} = 1 = 100$$

Case(iii) : under modulation



$$\mu = \frac{V_m}{V_c} = \frac{0.5A}{A} = 0.5 \cong 50\% \qquad \cong \frac{1.5A - 0.5A}{1.5A + 0.5A} = \frac{1A}{2A} = 0.5 = 50$$

Case (iv) : over modulation



$$\mu = \frac{V_m}{V_c} = \frac{1.5}{1} = 1.5 = 150\% \qquad \cong \frac{2.5 - (-0.5)}{2.5 + (-0.5)} = \frac{3}{2} = 1.5 \cong 150\%$$

→ $\mu = \frac{V_m}{V_c} \leq 1$ i.e as long as the % modulation is less than unity, there exists a one to one relationship between message signal and envelope of the modulated signal.

Condition 1: $\mu \leq 1 \quad \cong K_a m(t) \leq 1$

Condition 2: BW of $m(t)$ << BW of $c(t)$

Power relations in AM

$$m(t) = v_m(t) = V_m \cos \omega_m t$$

$$c(t) = v_c(t) = V_c \cos \omega_m t$$

$$v_{AM}(t) = V_c \cos \omega_c t + \frac{\mu V_c}{2} \cos(\omega_c + \omega_m)t + \frac{\mu V_c}{2} \cos(\omega_c - \omega_m)t$$

$$= \text{carrier} + \text{USB} + \text{LSB}$$

→ Carrier component of the modulated wave has the same amplitude as the unmodulated carrier i.e amplitude of the carrier is unchanged.

∴ energy is added or subtracted depending on the other components

→ The modulated wave contains extra energy in the two sidebands.

∴ modulated wave contains more power than the carrier, which had before modulation took place.

→ it is clear from the above equation that, the amplitude of the sidebands depends on the modulation index $\mu \left(= \frac{V_m}{V_c}\right)$, ∴ the total power in the modulated wave will also depend on the modulation index.

total power in the modulated wave is given by

$$P_t = \frac{V^2_{carrier}}{R} + \frac{V^2_{LSB}}{R} + \frac{V^2_{USB}}{R}$$

$$= P_c + P_{LSB} + P_{USB}$$

where all 3 voltages are RMS values and R is resistance of antenna through which power is dissi-

$$P_c = \frac{V^2_{carrier}}{R} = \frac{(V_c/\sqrt{2})^2}{R} = \frac{V_c^2}{2R}$$

$$P_{LSB} = \frac{V^2_{LSB}}{R} = \frac{(\frac{\mu V_c}{2}/\sqrt{2})^2}{R} = \frac{\mu^2 V_c^2}{8R}$$

$$P_{USB} = \frac{V^2_{USB}}{R} = \frac{(\frac{\mu V_c}{2}/\sqrt{2})^2}{R} = \frac{\mu^2 V_c^2}{8R}$$

$$P_t = P_c + P_{LSB} + P_{USB}$$

$$= \frac{V_c^2}{2R} + \frac{\mu^2 V_c^2}{8R} + \frac{\mu^2 V_c^2}{8R}$$

$$= \frac{V_c^2}{2R} + \frac{\mu^2 V_c^2}{4R} = \frac{V_c^2}{2R}\left[1 + \frac{\mu^2}{2}\right] = P_c\left[1 + \frac{\mu^2}{2}\right]$$

for $\mu = 1$ i.e 100% modulation

$$= \frac{V_c^2}{2R}\left[1 + \frac{1}{2}\right] = 1.5\,\frac{V_c^2}{2R} = 1.5\,P_c$$

$$P_{LSB} = P_{USB} = \frac{\mu^2 V_c^2}{8R} = \frac{V_c^2}{2R}\left[\frac{\mu^2}{4}\right] = P_c\,\frac{\mu^2}{4}$$

Current relations in AM

$$P_t = P_c\left[1 + \frac{\mu^2}{2}\right]$$

$$I_t^2 \cdot R = I_c^2 \cdot R\left[1 + \frac{\mu^2}{2}\right]$$

$$I_t = I_c\sqrt{1 + \frac{\mu^2}{2}}$$

I_c → carrier current

I_t → modulated signal current

Efficiency

→ It can be defined as the ratio of power in sidebands to total power, because the side-bands are containing the actual information.

$$\% \eta = \frac{\text{Power in sidebands}}{\text{total power}}$$

$$= \frac{P_{USB} + P_{OSB}}{P_t}$$

$$= \frac{\frac{u^2 V_c^2}{8R} + \frac{u^2 V_c^2}{8R}}{\frac{V_c^2}{2R}\left[1 + \frac{u^2}{2}\right]} = \frac{\frac{u^2 V_c^2}{4R}}{\frac{V_c^2}{2R}\left[1 + \frac{u^2}{2}\right]}$$

$$= \frac{\frac{u^2}{2}}{\frac{2+u^2}{2}} = \frac{u^2}{2+u^2}$$

for $u = 1$ i.e 100% modulation

$$= \frac{1}{2+1} = \frac{1}{3} \times 100 = 33.3\ \%$$

i.e only 33.3 % of power is utilized and the remaining power is wasted by the transmission of carrier along with sidebands.

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Multitone modulation

Let $m(t) = v_m(t) = V_{m_1} \cos \omega_{m_1} t + V_2 \cos \omega_{m_2} t$

$c(t) = v_c(t) = V_c \cos \omega_c t$

modulated signal

$$v_{AM}(t) = V_{AM} \cos \omega_c t$$

$$= [V_c + m(t)] \cos \omega_c t$$

$$= \left[V_c + V_{m_1} \cos \omega_{m_1} t + V_{m_2} \cos \omega_{m_2} t\right] \cos \omega_c t$$

$$= V_c \left[1 + \frac{V_{m_1}}{V_c} \cos \omega_{m_1} t + \frac{V_{m_2}}{V_c} \cos \omega_{m_2} t\right] \cos \omega_c t$$

$$= V_c \left[1 + \mu_1 \cos \omega_{m_1} t + \mu_2 \cos \omega_{m_2} t\right] \cos \omega_c t$$

where $\mu_1 = \frac{V_{m_1}}{V_c}$ & $\mu_2 = \frac{V_{m_2}}{V_c}$

$$= V_c \left[1 + \frac{1}{V_c} V_{m_1} \cos \omega_{m_1} t + \frac{1}{V_c} V_{m_2} \cos \omega_{m_2} t\right] \cos \omega_c t$$

$$= V_c \left[1 + k_a m_1(t) + k_a m_2(t)\right] \cos \omega_c t$$

where $k_a = \frac{1}{V_c}$ = amplitude sensitivity

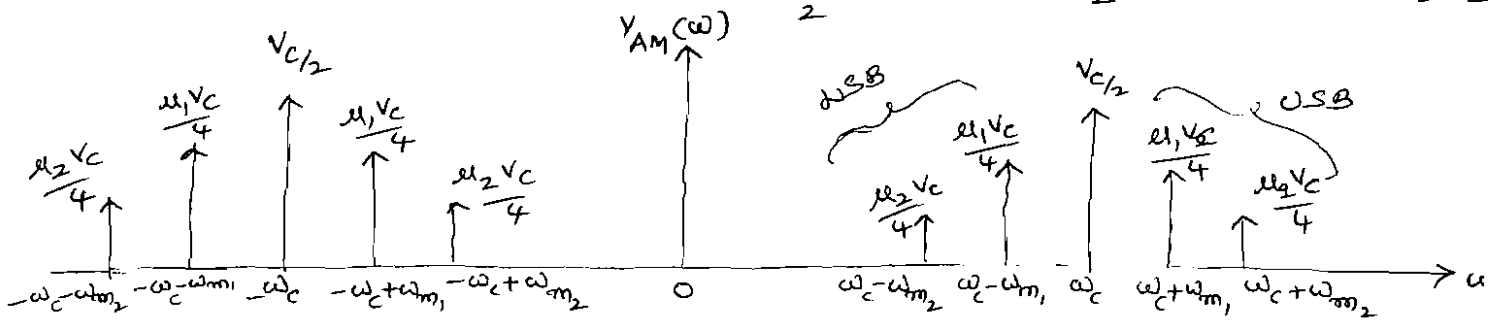
$m_1(t) = V_{m_1} \cos \omega_{m_1} t$

$m_2(t) = V_{m_2} \cos \omega_{m_2} t$

$$= V_c \cos \omega_c t + \mu_1 V_c \cos \omega_{m_1} t \cos \omega_c t + \mu_2 V_c \cos \omega_{m_2} t \cos \omega_c t$$

$$= V_c \cos \omega_c t + \frac{\mu_1 V_c}{2} \left[\cos(\omega_c + \omega_{m_1}) t + \cos(\omega_c - \omega_{m_1}) t\right]$$

$$+ \frac{\mu_2 V_c}{2} \left[\cos(\omega_c + \omega_{m_2}) t + \cos(\omega_c - \omega_{m_2}) t\right]$$



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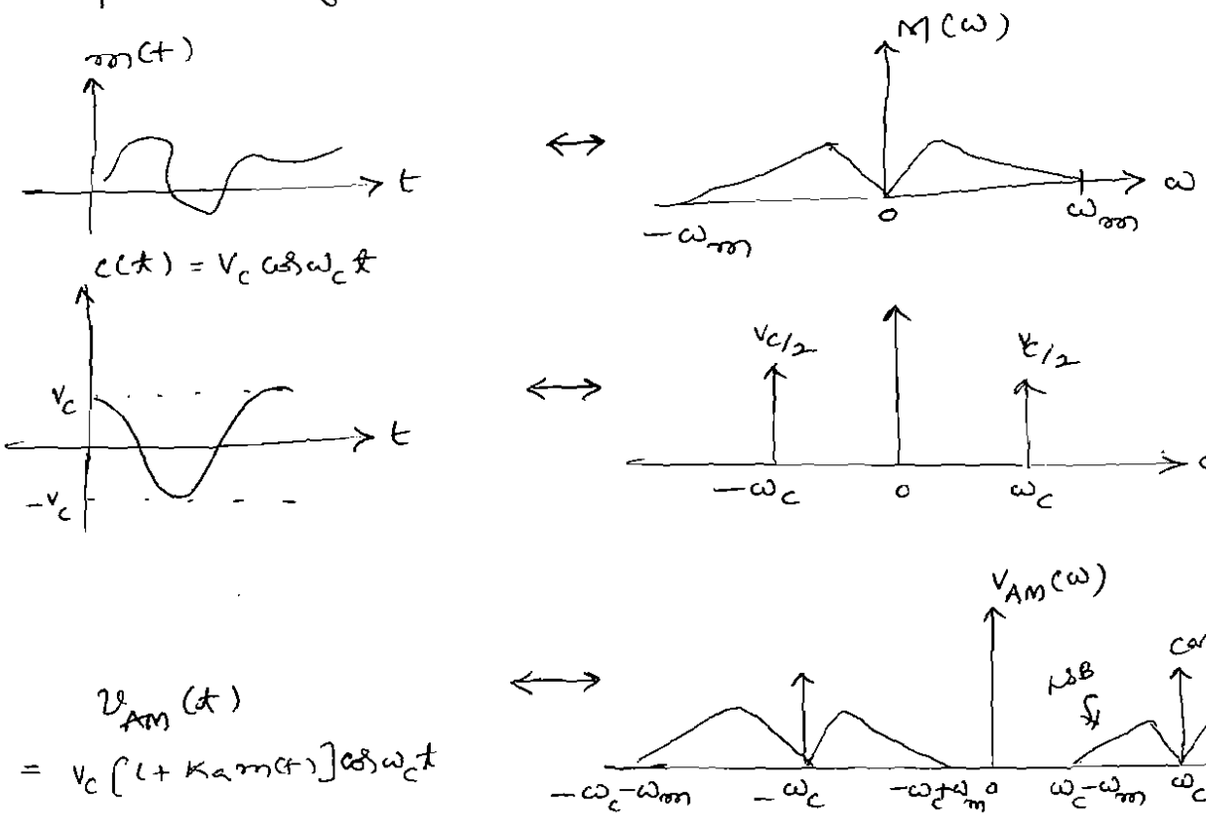
IIIly when $m(t)$ is containing infinite no. of waves, the spectrum of modulated signal is as follows



$$v_{AM}(t) = V_c[1 + K_a m(t)]\cos\omega_c t$$

Power relations

$$m(t) = V_{m_1}\cos\omega_{m_1}(t) + V_{m_2}\cos\omega_{m_2} t$$

$$c(t) = V_c \cos\omega_c t$$

$$v_{AM}(t) = V_c\cos\omega_c t + \frac{\mu_1 V_c}{2}\left[\cos(\omega_c+\omega_{m_1})t + \cos(\omega_c-\omega_{m_1})t\right]$$

$$+ \frac{\mu_2 V_c}{2}\left[\cos(\omega_c+\omega_{m_2})t + \cos(\omega_c-\omega_{m_2})t\right]$$

Total power transmitted

$$P_t = P_c + P_{LSB} + P_{USB}$$

$$= \frac{(V_c/\sqrt{2})^2}{R} + \frac{(\frac{\mu_1 V_c}{2}/\sqrt{2})^2}{R} + \frac{(\frac{\mu_2 V_c}{2}/\sqrt{2})^2}{R} + \frac{(\frac{\mu_1 V_c}{2}/\sqrt{2})^2}{R} + \frac{(\frac{\mu_2 V_c}{2}/\sqrt{2})^2}{R}$$

$$= \frac{V_c^2}{2R} + 2\left[\left(\frac{\mu_1 V_c}{2\sqrt{2}}\right)^2/R + \left(\frac{\mu_2 V_c}{2\sqrt{2}}\right)^2/R\right]$$

$$= \frac{V_c^2}{2R} + \frac{V_c^2}{4R}\left[\mu_1^2 + \mu_2^2\right] \qquad \checkmark\ \mu^2 = \mu_1^2 + \mu_2^2$$

$$= \frac{V_c^2}{2R} + \frac{V_c^2}{4R}\mu^2 = \frac{V_c^2}{2R}\left[1 + \frac{\mu^2}{2}\right] = P_c\left[1 + \frac{\mu^2}{2}\right]$$

Ily

for u can can be calculated for any no of components.

$$u = u_1^2 + u_2^2 + \text{- - - - -}$$

$$P_t = P_c \left[1 + \frac{u^2}{2}\right]$$

Efficiency:

$$\therefore \eta = \frac{\text{Power in sidebands}}{\text{total power transmitted}}$$

$$= \frac{\frac{V_c^2}{2R} u^2}{\frac{V_c^2}{2R}\left[1 + \frac{u^2}{2}\right]}$$

$$= \frac{\frac{u^2}{2}}{\frac{2+u^2}{2}} = \frac{u^2}{2+u^2} =$$

if $u = 1$

$$= \frac{1^2}{2+1^2} = \frac{1}{3} = .33 \simeq 33\ \%.$$

Generation of AM waves

→ The techniques for generating Amplitude modulated waves can be classified into 2 categories.

(i) Low level modulation
(ii) High level modulation

→ In low level modulation model, the generation of AM waves takes place in the initial stage of amplification i.e at a low power level. The generated AM signal is then amplified using no of amplifier stages.

→ In high level modulation model, modulation takes place in the final stage of amplification and therefore modulation circuitry has to handle high power.

→ The following two techniques are well suited for low power modulation purposes.

(i) Square law modulator
(ii) Switching modulator

The above two techniques are non-linear modulators

→ A simple diode or transistor or FET can be used as non-linear modulator by restricting the operation over the non-linear region of it's characteristics.

→ The i/p to the diode is kept so small, that the diode operation in a non-linear region of it's V-I characteristics.

→ This method is useful for only small signal Amplitude modulation.

Square law modulator

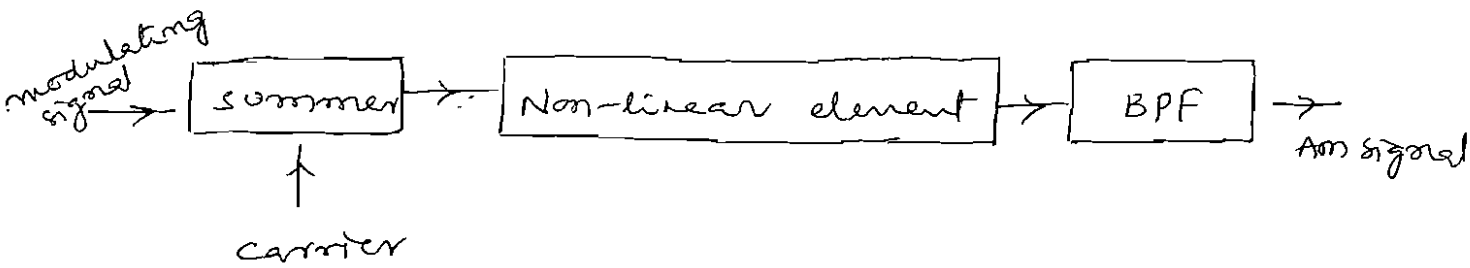
→ It contains 3 elements

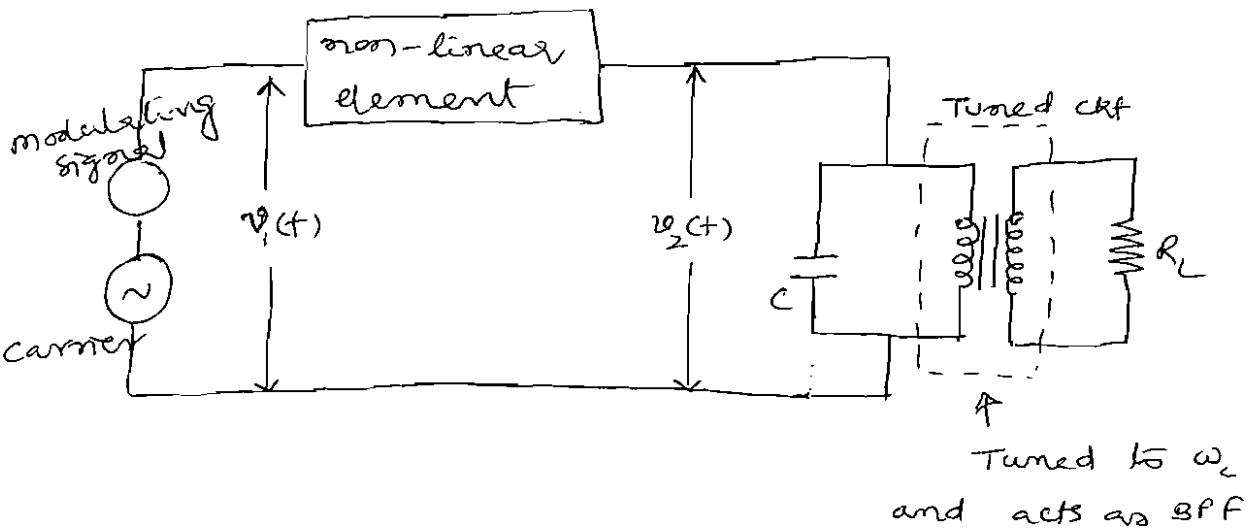
(i) Summer : for summing carrier and modulating signal

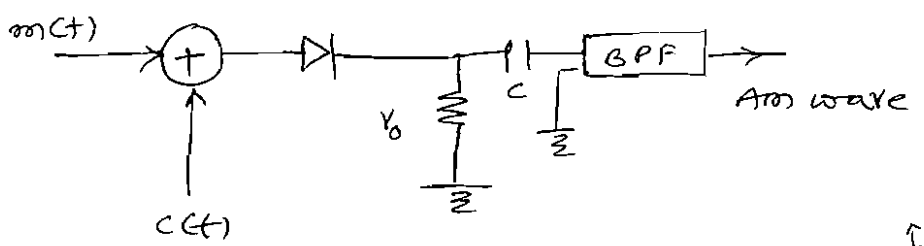
(ii) Non-linear element : for implementing square law modulator

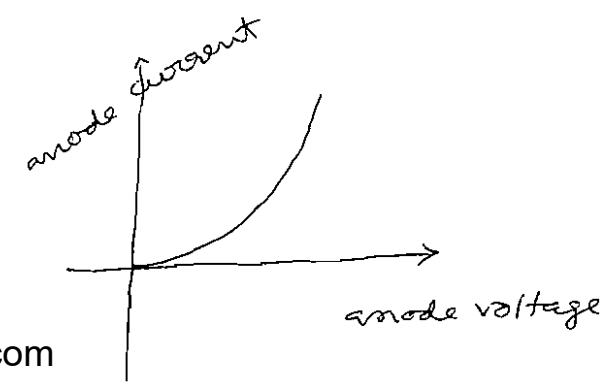
(iii) Bandpass filter (BPF) : for extracting the desired modulation products

Block diagram:









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→ The output and input relationship of non linear devices is as follows

$$v_0 = a_1 v_i + a_2 v_i^2 + a_3 v_i^3 + \cdots$$

if v_i is small, first two terms are significant and remaining terms can be neglected.

$$\therefore \boxed{v_0 = a_1 v_i + a_2 v_i^2}$$

→ When a non-linear element like diode is suitably biased and operated in a restricted portion of it's characteristic curve i.e if the signal applied is to the diode is relatively weak, then we find the transfer characteristic of the diode load resistor condition can be represented closely by a square law

$$v_2(t) = a_1 v_1(t) + a_2 v_2^2(t) \quad \rightarrow (1)$$

where a_1 and a_2 are constants

and i/p voltage $v_1(t) = m(t) + c(t)$

$$= m(t) + V_c \cos \omega_c t \quad \rightarrow (2)$$

substituting eqn (2) in (1), gives

$$v_2(t) = a_1 [m(t) + V_c \cos \omega_c t] + a_2 [m(t) + V_c \cos \omega_c t]^2$$

$$= a_1 m(t) + a_1 V_c \cos \omega_c t + a_2 m^2(t) + a_2 V_c^2 \cos^2 \omega_c t + 2 a_2 m(t) V_c \cos \omega_c t$$

$$= a_1 m(t) + a_2 m^2(t) + a_2 V_c^2 \left[\frac{1 + \cos 2\omega_c t}{2}\right] + a_1 V_c \left[1 + \frac{2a_2}{a_1} m(t)\right] \cos \omega_c t$$

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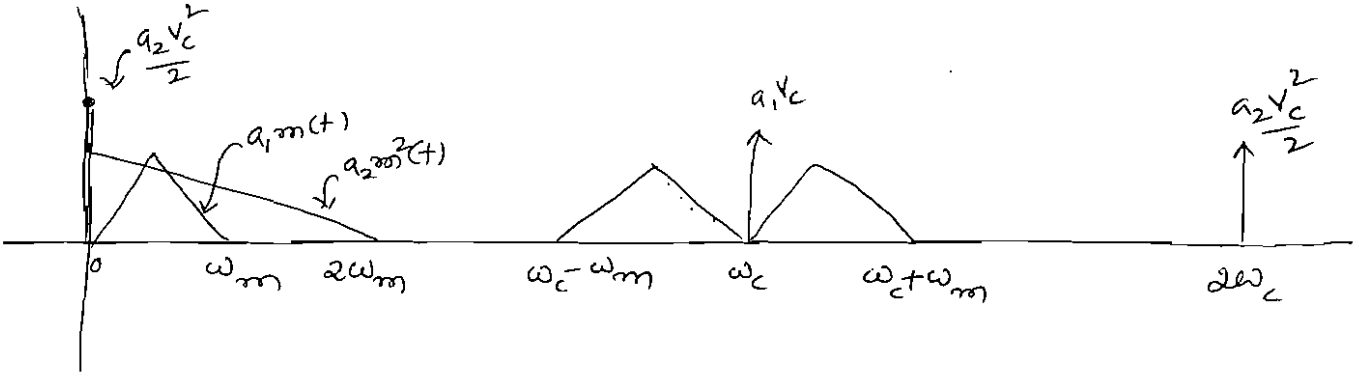
$$= a_1 V_c \left[1 + \frac{2a_2}{a_1} m(t)\right] \cos \omega_c t + a_1 m(t) + a_2 m^2(t) + \frac{a_2 V_c^2}{2} + \frac{a_2 V_c^2}{2} \cos 2\omega_c t \quad \rightarrow (3)$$

AM wave with amplitude sensitivity $K_a = \frac{2a_2}{a_1}$

unwanted components and these components can be removed by appropriate (bandpass) filtering

(remember from convolution property that $m^2(t)$ has the twice the BW of $m(t)$)



conditions:

$$\omega_c - \omega_m \gg 2\omega_m$$

&

$$\omega_c \gg 3\omega_m$$

→ The eqn (3) gives the resulting voltage developed across the primary winding of the transformer. The first terms of eqn (3) is the desired AM wave and $K_a = \frac{2a_2}{a_1}$ is the amplitude sensitivity. ∴ The remaining unwanted terms present in the above equation can be eliminated by appropriate filtering method

Specifications of filter:

midband frequency : ω_c

BW : $2\omega_m$

ω_c : $> 3\omega_m$

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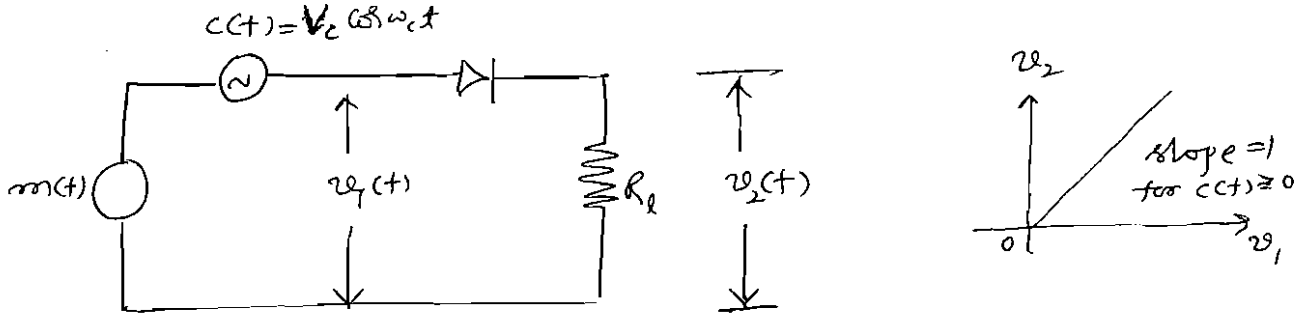
Switching Modulator

The switching modulator is shown below.



→ Here, the diode is assumed to act as ideal switch i.e it presents zero impedance when it is forward biased and infinite impedance when it is reverse biased.

→ The diode switch is controlled by carrier wave c(t) and assume that the carrier voltage c(t) applied to the diode is large in amplitude.

→ The i/p voltage

$$v_1(t) = m(t) + c(t)$$
$$= m(t) + V_c \cos \omega_c t \rightarrow (1)$$

$\because m(t) \ll V_c$

∴ The resulting load voltage

$$v_2(t) = v_1(t) \quad \text{if } c(t) > 0$$
$$0 \quad \text{if } c(t) < 0 \rightarrow (2)$$

∴ we may thus approximate the transfer characteristic curve of the diode load resistor combination by a piecewise linear characteristic

→ i.e the load voltage periodically varies between the values $v_1(t)$ and zero at a rate equal to the carrier frequency ω_c.

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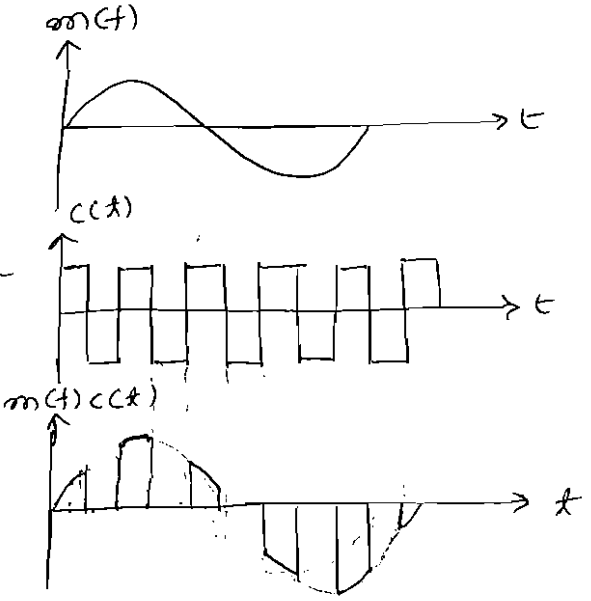
→ Thus, a modulating signal which is weak compared with the carrier wave, we can replace the non-linear behavior of a diode by an approximately equivalent linear time varying operation.



→ Eqn ② can be written as

$$v_2(t) \cong v_1(t) \cdot g_p(t)$$

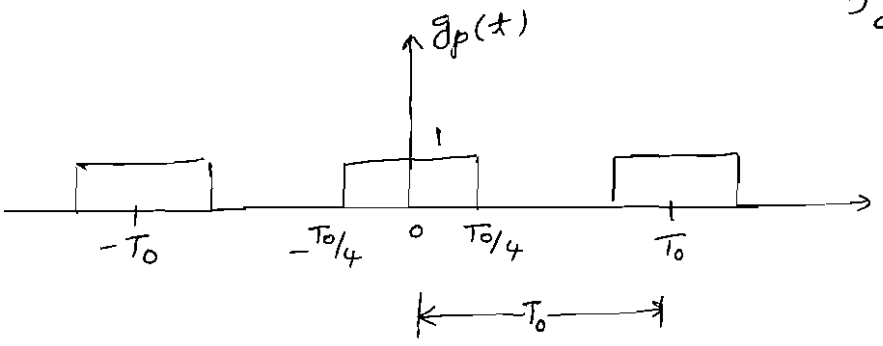
$$\cong [m(t) + V_c \cos\omega_c t] \cdot g_p(t)$$

$$\cong [m(t) + c(t)]\, g_p(t)$$

where $g_p(t)$ is a periodic pulse train

duty cycle = one half of time period

$$T_0 = \frac{1}{f_c}$$



→ using fourier series, $g_p(t)$ can be written as

$$g_p(t) = \frac{1}{2} + \frac{2}{\pi} \sum_{n=1}^{\infty} \frac{(-1)^{n-1}}{2n-1} \cos[\omega_c t\,(2n-1)]$$

$$= \frac{1}{2} + \frac{2}{\pi}\cos\omega_c t + \text{odd harmonic components} \quad \rightarrow ④$$

substituting eqn ④ in eqn ③, we get

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$$v_2(t) = [V_c \cos\omega_c t + m(t)]\left\{\frac{1}{2} + \frac{2}{\pi}\cos\omega_c t + \text{odd components}\right.$$

$$= \frac{V_c}{2}\cos\omega_c t + \frac{1}{2}m(t) + V_c\frac{2}{\pi}\cos^2\omega_c t + \cdots$$

$2 \times V_c \times \frac{2}{\pi} m(t)\cos\omega_c t$ + some unwanted component

$$= \frac{V_c}{2}\left[1 + \frac{4}{\pi V_c}m(t)\right]\cos\omega_c t + \frac{1}{2}m(t) + \frac{2V_c}{\pi}\cos^2\omega_c t + \cdots$$

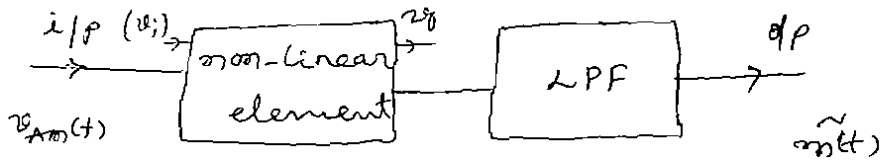
(the underbrace: AM wave; unwanted components)

AM wave

$k_a = \frac{4}{\pi V_c}$ amplitude sensitivity

→ all unwanted components can be removed using appropriate filtering.

Square law detector



$$v_o = a_1 v_i + a_2 v_i^2$$

here $v_i = V_c [1 + K_a m(t)] \cos \omega_c t$

$$\therefore v_o = a_1 [V_c [1 + K_a m(t)] \cos \omega_c t + a_2 \{ V_c [1 + K_a m(t)] \cos \omega_c t \}^2$$

$$= a_1 V_c [1 + K_a m(t)] \cos \omega_c t + a_2 [V_c \cos \omega_c t + V_c K_a m(t) \cos \omega_c t]^2$$

$$= a_1 V_c [1 + K_a m(t)] \cos \omega_c t + a_2 V_c^2 \cos^2 \omega_c t + a_2 V_c^2 K_a^2 m^2(t) \cos^2 \omega_c t + 2 a_2 V_c \cos \omega_c t \; V_c K_a m(t) \cos \omega_c t$$

$$= a_1 V_c [1 + K_a m(t)] \cos \omega_c t + [a_2 V_c^2 + a_2 V_c^2 K_a^2 m^2(t) + 2 a_2 V_c^2 K_a m(t)] \cos^2 \omega_c t$$

$$= a_1 V_c [1 + K_a m(t)] \cos \omega_c t + \frac{a_2 V_c^2}{2} [1 + K_a^2 m^2(t) + 2 K_a m(t)] [1 + \cos 2\omega_c t]$$

$$= a_1 V_c [1 + K_a m(t)] \cos \omega_c t + \frac{a_2 V_c^2}{2} [1 + K_a m(t)]^2 [1 + \cos 2\omega_c t]$$

$$= a_1 V_c [1 + K_a m(t)] \cos \omega_c t + \frac{a_2 V_c^2}{2} [1 + K_a m(t)]^2 \cdot 1 + \frac{a_2 V_c^2}{2} [1 + K_a m(t)]^2 \cos 2\omega_c t$$

$$= a_1 V_c [1 + K_a m(t)] \cos \omega_c t + \frac{a_2 V_c^2}{2} + a_2 V_c^2 K_a m(t) + \frac{a_2 V_c^2}{2} K_a^2 m^2(t) + \frac{a_2 V_c^2}{2} [1 + K_a m(t)]^2 \cos 2\omega_c t$$

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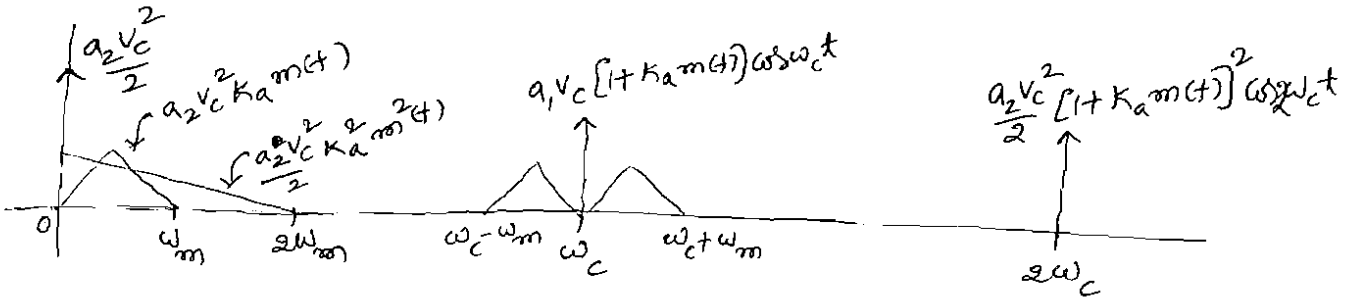

→ The d.c component and all frequency components whose frequency is more than ω_m can be removed by using LPF.

→ Still the term $\frac{a_2V_c^2K_a^2m^2(t)}{2}$ is interfering with $a_2V_c^2K_am(t)$

The ratio between wanted and unwanted terms is given by

$$\frac{\text{wanted}}{\text{unwanted}} : \frac{a_2V_c^2K_am(t)}{\frac{a_2V_c^2}{2}K_a^2m^2(t)}$$

$$: \frac{2}{K_am(t)} = \frac{2}{u}$$

→ for this ratio to be large $K_am(t) << 1$

i.e $u << 1$

i.e the modulation index must be selected so small to avoid distortion in case of square law method.

→ we know that, for better efficiency the modulation index u should be as high as possible ($<=1$)

∴ Square law method is generally not preferred for detection purpose.

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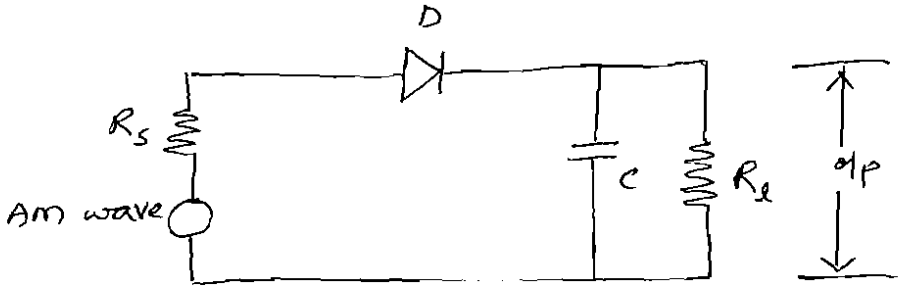
Envelope Detector (or) diode detector

→ An envelope detector is a simple and highly effective device that is well suited for the demodulation of narrow band AM wave (i.e the carrier frequency is large compared with the modulating signal frequency BW for which the % modulation is less than 100%. In envelope detector, the o/p follows the envelope of the modulated signal, hence the name.

→ The envelope detector circuit is shown below.

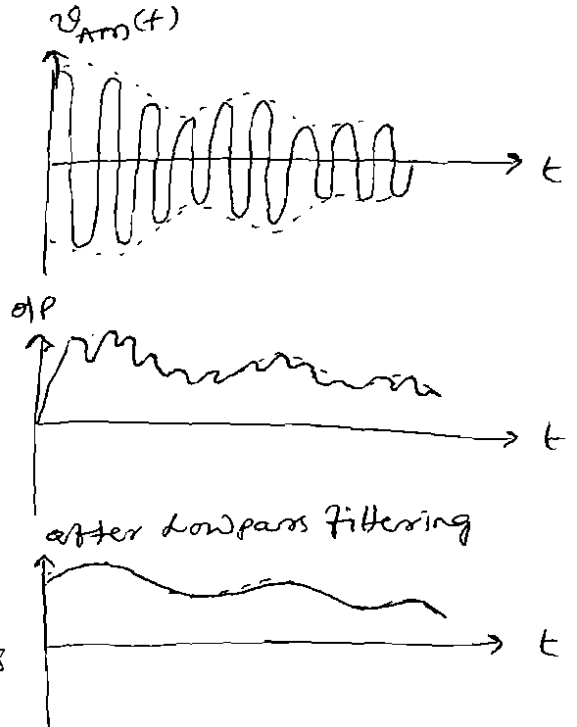


operation:

→ during the +ve half cycle of the i/p AM wave, the diode is forward biased and the capacitor C charges up rapidly to the peak value of the i/p signal.

→ When the i/p signal falls below this value, the diode becomes reverse biased and the capacitor C discharges slowly thro the load resistor R_l.

The discharging process continues until the next +ve half cycle.



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→ When the i/p signal becomes greater than the voltage across capacitor, the diode conducts again and the process is repeated.

→ assume diode is ideal.

offers zero impedance during forward biased time and infinite impedance during reverse biased time.

→ we also assume that the AM wave applied to the envelope detector is supplied by a voltage source of internal impedance R_s.

→ The charging time constant $R_s C$ must be small compared with carrier period $\frac{1}{f_c}$

$$R_s C \ll \frac{1}{f_c}$$

→ Discharging time constant $R_l C$ must be very high enough to ensure that the capacitor discharges slowly through the load resistor R_l between +ve peaks of the carrier wave. at the same moment, it should not be so long that the capacitor voltage will not discharge at the maximum rate of change of the modulating signal.

$$\frac{1}{f_c} \ll R_l C \ll \frac{1}{\omega_m}$$

→ The capacitor voltage or detector o/p is very nearly to the envelope of the AM wave.

→ The o/p usually has a small ripples at the carrier frequency rate, it can easily be removed by low pass filtering.

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Problems:

P1: A commercial AM station is broadcasting with an average transmitted carrier power of 10 KW. The modulation index is set at 0.707 for a sinusoidal message signal. Find the transmission power, efficiency and power in the sidebands of the transmitted signal

Soln:

(i) Total power transmitted

$$P_t = P_c\left[1+\frac{\mu^2}{2}\right]$$

$$= 10\times10^3\left[1+\frac{(0.707)^2}{2}\right] = 12.5 \text{ KW}$$

(ii) % efficiency

$$\%\,\eta = \frac{P_{SB}}{P_t}\times 100$$

$$= \frac{\frac{\mu^2 P_c}{2}}{P_c\left[1+\frac{\mu^2}{2}\right]} = \frac{\frac{(0.707)^2}{2}}{\left[1+\frac{(0.707)^2}{2}\right]} = 20\%$$

(iii) Side band power $= \frac{\mu^2 P_c}{2}$

$$= \frac{(0.707)^2}{2}\times 10\times10^3 = 2.5 \text{ KW}$$

P2 A complex modulating wave consisting of a sine wave of amplitude 3V and frequency 1 KHz plus a cosine wave of amplitude of 5V and frequency 3 KHz is amplitude modulated by a sine carrier of 500KHz and 50V peak. Determine the average power transmitted

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when a wave is fed to a 50Ω load.

Soln:

$$v_m(t) = 3 \sin(2\pi \times 1\times10^3 \times t) + 5\cos(2\pi \times 3\times10^3 \times t)$$

$$v_c(t) = 50 \sin(2\pi \times 500 \times 10^3 \times t)$$

are power transmitted

$$P_t = P_c\left[1 + \frac{\mu^2}{2}\right] = \frac{V_c^2}{2R}\left[1 + \frac{\mu^2}{2}\right]$$

$V_c = 50\,V$

$R = 50\,\Omega$

$$\mu^2 = \mu_1^2 + \mu_2^2$$

$$= \frac{V_{m_1}}{V_c} + \frac{V_{m_2}}{V_c}$$

$$= \frac{3}{50} + \frac{5}{50}$$

$$= \frac{50^2}{2\times50}\left[1 + \frac{(\frac{3}{50})^2 + (\frac{5}{50})^2}{2}\right]$$

$$= 25.17\ W$$

P3 The total transmitted power content of Am signal is 1000 Watts. Determine the power being transmitted at the carrier frequency and each of the sidebands when the % modulation is 100.

$$P_t = P_c + P_{USB} + P_{LSB}$$

$$= P_c + P_c\frac{\mu^2}{4} + P_c\frac{\mu^2}{4}$$

$$= P_c + P_c\frac{\mu^2}{2}$$

if $\mu = 1$

$$= P_c + \frac{P_c}{2}$$

$$= 1.5\,P_c$$

$$1000 = 1.5\,P_c$$

$$P_c = 666.67 \text{ Watts}$$

$$P_{SB} = P_t - P_c$$

$$= 1000 - 666.67 = 333.3 \text{ Watts}$$

$$P_{LSB} = P_{USB} = \frac{P_{SB}}{2} = \frac{333.3}{2}$$

$$= 166.67 \text{ Watts}$$

P4 An AM signal is given by

$$v_{Am}(t) = 10\cos 2\pi 10^6 t + 5\cos 2\pi 10^6 t \cos 2\pi 10^3 t + 2\cos 2\pi 10^6 t \cos 4\pi 10^3 t$$

Find the various frequency components and the corresponding modulation indices. Draw the spectrum, BW, modulated power, sideband power and modulation index.

Soln:

$$v_{Am}(t) = 10\cos 2\pi 10^6 t + 5\cos 2\pi 10^6 t \cos 2\pi 10^3 t + 2\cos 2\pi 10^6 t \cos 4\pi 10^3 t$$

$$= 10\cos 2\pi 10^6 t \left[1 + 0.5\cos 2\pi 10^3 t + 0.2\cos 4\pi 10^3 t\right]$$

$V_c = 10V \quad \mu_1 = 0.5 \quad \mu_2 = 0.2$

$\omega_c = 2\pi 10^6 \quad \omega_{m_1} = 2\pi 10^3 \quad \omega_{m_2} = 2\pi \times 2 \times 10^3$

$f_c = 1000\,KHz \quad f_{m_1} = 1\,KHz \quad f_{m_2} = 2\,KHz$

$= 1\,mHz \quad = 0.001\,mHz \quad = 0.002\,mHz$

frequencies

USB terms

$f_c + f_{m_1} = 1\,mHz + 0.001\,mHz = 1.001\,mHz$

$f_c + f_{m_2} = 1\,mHz + 0.002\,mHz = 1.002\,mHz$

LSB terms

$f_c - f_{m_1} = 1\,mHz - 0.001\,mHz = 0.999\,mHz$

$f_c - f_{m_2} = 1\,mHz - 0.002\,mHz = 0.998\,mHz$

magnitudes

for $f_{m_1} \longrightarrow \frac{\mu_1 V_c}{2} = \frac{0.5 \times 10}{2} = 2.5\,V$

for $f_{m_2} \longrightarrow \frac{\mu_2 V_c}{2} = \frac{0.2 \times 10}{2} = 1\,V$

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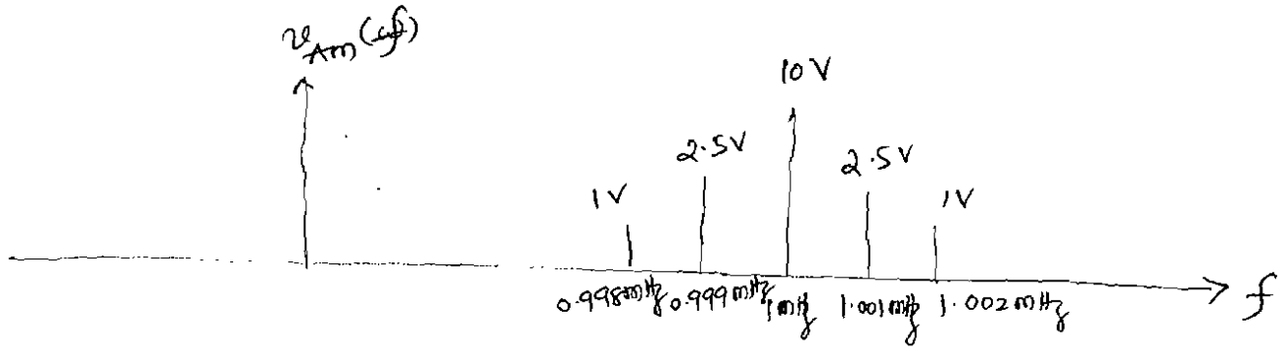

carrier power $P_c = \frac{V_c^2}{2R} = \frac{10^2}{2} = 50$ watts

where $R = 1\Omega$

$$P_t = P_c\left[1 + \frac{\mu^2}{2}\right]$$

$$= 50\left[1 + \frac{(0.29)^2}{2}\right]$$

$$= 52.1 \text{ watts}$$

$$\mu^2 = \mu_1^2 + \mu_2^2$$

$$= 0.5^2 + 0.2^2$$

$$= 0.25 + 0.04$$

$$= 0.29$$

$$P_{SB} = P_t - P_c$$

$$= 52.1 - 50$$

$$= 2.1 \text{ watts}$$

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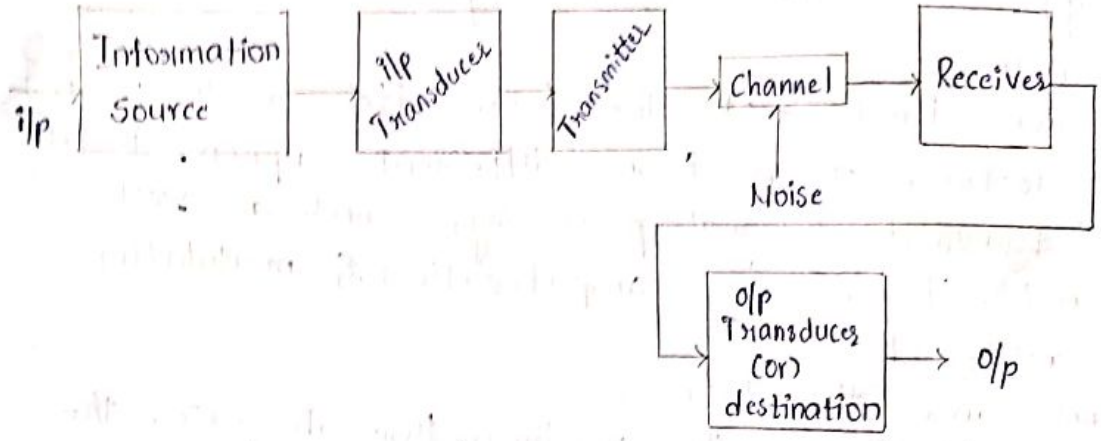
Analog Communications

Communication:
The process of establishing a connection b/w 2 points for information interchange is called as communication.
* The process of exchanging information b/w any 2 points is called as communication.
The electronic equipment which are used for the purpose of communication is called as communication equipments.
When different communication equipments are connected together it forms a system called as communication system.

Elements of Communication System (OSI)
Block diagram of Communication system:



Block diagram of Analog Communication System

Transducer:
It is an electronic device which converts one-form of energy into another form & Vice Versa.
Ex: Electromagnetic waves → Electric signals

Transmitter:
The o/p of the transducer are low level signals.
Transmitter performs 3 operations.
1. Amplification
2. Modulation
3. Processing

DeModulation:
The process of recovering the signal from the noise signal.

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Information Source:
The main source of information source is to produce the required message which has to be transmitted. The input source may be a voice signal, Music signal, Video signal (or) a data from a computer

Input Transducer:
A transducer is a device which converts one form of energy into another form. The message from the I/P source may or may not be in electric form. In case when the message is not in electric form an input transducer is used to convert it into a time varying electrical signal. One example of transducer is microphone which converts sound energy into electrical energy.

Transmitter:
The main function of the transmitter is to process the electrical signal from different aspects. Inside the transmitter signal processings such as restriction of audio frequencies, amplification & modulation are achieved.

Channel and the Noise:
The channel means the medium through which the message signal travels from transmitter to the receiver. In other words we can say that the function of a channel is to provide a physical connection b/w the transmitter and receiver

During the process of transmission and reception the signal gets distorted due to the noise introduced in the system. Noise is an unwanted signal which tends to interfere with the required message signal

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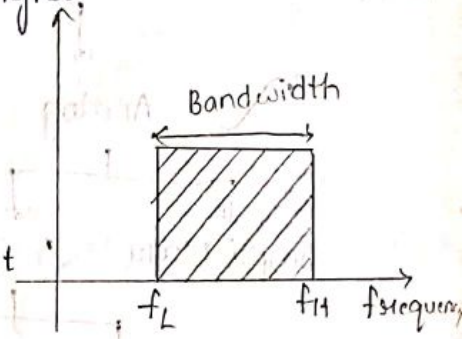
Receiver :-
The main function of the receiver is to reproduce the original message signal in electric form. The process of recovering (or) reproducing the original message signal is called as demodulation. Demodulation is the reverse process of modulation carried out in transmitter block.

Output Transducer :-
Output transducer is to convert the electrical signal coming out from the receiver section into its original form.

Destination :-
Destination is the final stage which produces the message signal in its original form.
For example: In radio broad casting, the destination is a loud speaker.

Concept of Band width :-
The portion of electromagnetic spectrum occupied by a signal can be called as a band width. (or) The frequency range over which an information signal is transmitted is called as band width.
Band width is the difference between upper and lower frequency limits of a signal.

* Band width = $f_H - f_L$



The table below shows the frequency ranges and the band width requirement of different types of signals.

Type of signal	Frequency range	Bandwidth
Voice signal	300 - 3400Hz	3100Hz
Music signal	20 - 15000 Hz	14980Hz
Video signal	0 - 5MHz	5MHz
Data from Computer (if data cables are used)	300 - 3400Hz	3100Hz

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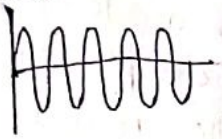
Modulation Process:

Generally, the purpose of any communication system is to delievers a message (or) information from the i/p source to the destination in a recognizable form. To do this, the transmitter modifies the information (or) message signal into a form which is suitable for the transmission over the channel. This modification is achieved by using the process named as 'modulation'

Modulation :- ****

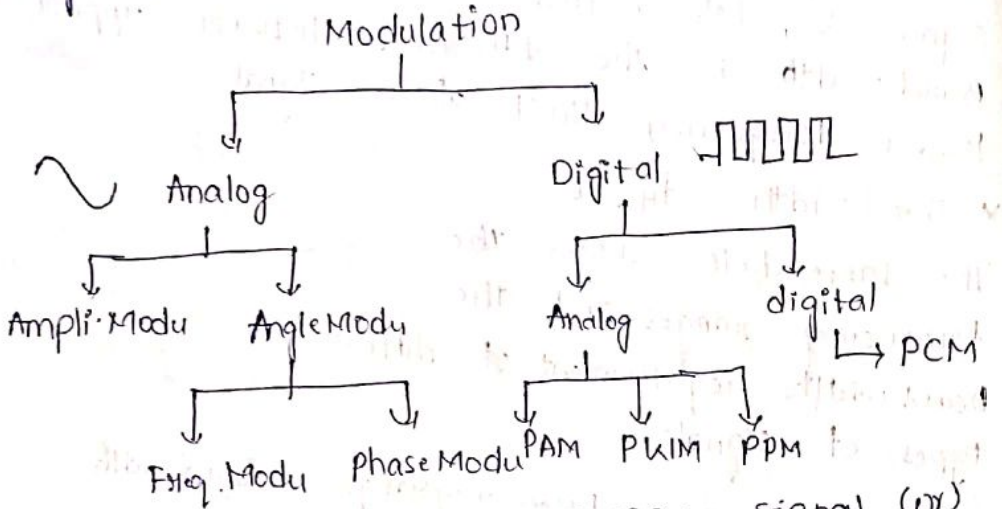
The process of changing (or) varying characteristics of a carrier signal (amplitude, frequency, phase) in accordance with the instantaneous values of a message signal is called as 'modulation'.

Carrier Signal - high frequency signal]



Types of Modulations:-

Basically, modulation is classified into 2 types depending on the type of the carrier signal.



→ input signal is known as message signal (or) information signal (or) modulating signal (or) base band signal.

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Amplitude Modulation:-
The process of changing the amplitudes of a carrier signal in according to instantaneous values of the amplitudes of message signal keeping frequency and phase constant is called as amplitude modulation.

Frequency Modulation:-
The process of changing the frequency of a carrier signal according to instantaneous values of the frequencies of message signal keeping amplitude and phase constant is called as frequency modulation.

Phase Modulation:-
The process of changing the phase of a carrier signal according to instantaneous values of the phases of message signal keeping amplitude and frequency constant is called as phase modulation.

Need for modulation:-
1. To reduce the height of antenna.
when free space is selected as a transmission medium, then antennas are used for transmitting and receiving the signals.
Suppose if we transmit a 5KHz signal then the height of the antenna required to be constructed is given as $l = \frac{\lambda}{4} = \frac{c}{4f} = \frac{3\times10^8}{4\times5\times10^3} = 15000$mts.
This is practically not possible to construct an antenna of such height.
If we translate a 5KHz signal into a high frequency 3MHz signal by using modulation technique. Then, the height of the antenna required to be constructed is given as $l = \frac{\lambda}{4} = \frac{c}{4f} = \frac{3\times10^8}{4\times3\times10^6} = 25$mts.
This is practically possible to construct an antenna of such height

2. To increase the range of communication
Generally, most of the message signal are of low frequency type. They get easily attenuated and effected by noise signals. So, the low frequency msg signals cannot be transmitted directly

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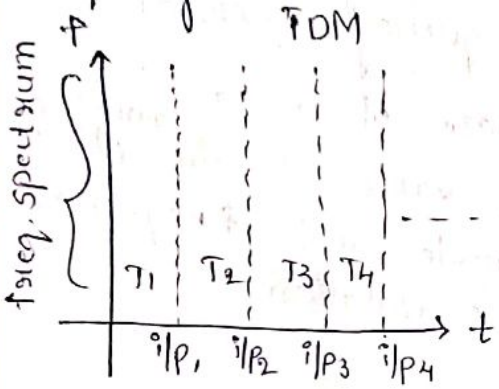
over long distances. In order to transmit over long distances, modulation is needed.

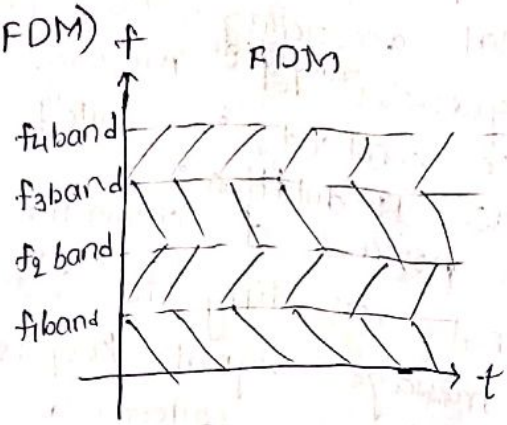
3. It allows multiplexing.

The process of transmitting two or more i/p signals through a single channel is called as multiplexing. Multiplexing is classified into 2 types.

Time division Multiplexing (TDM)

Frequency " " (FDM)

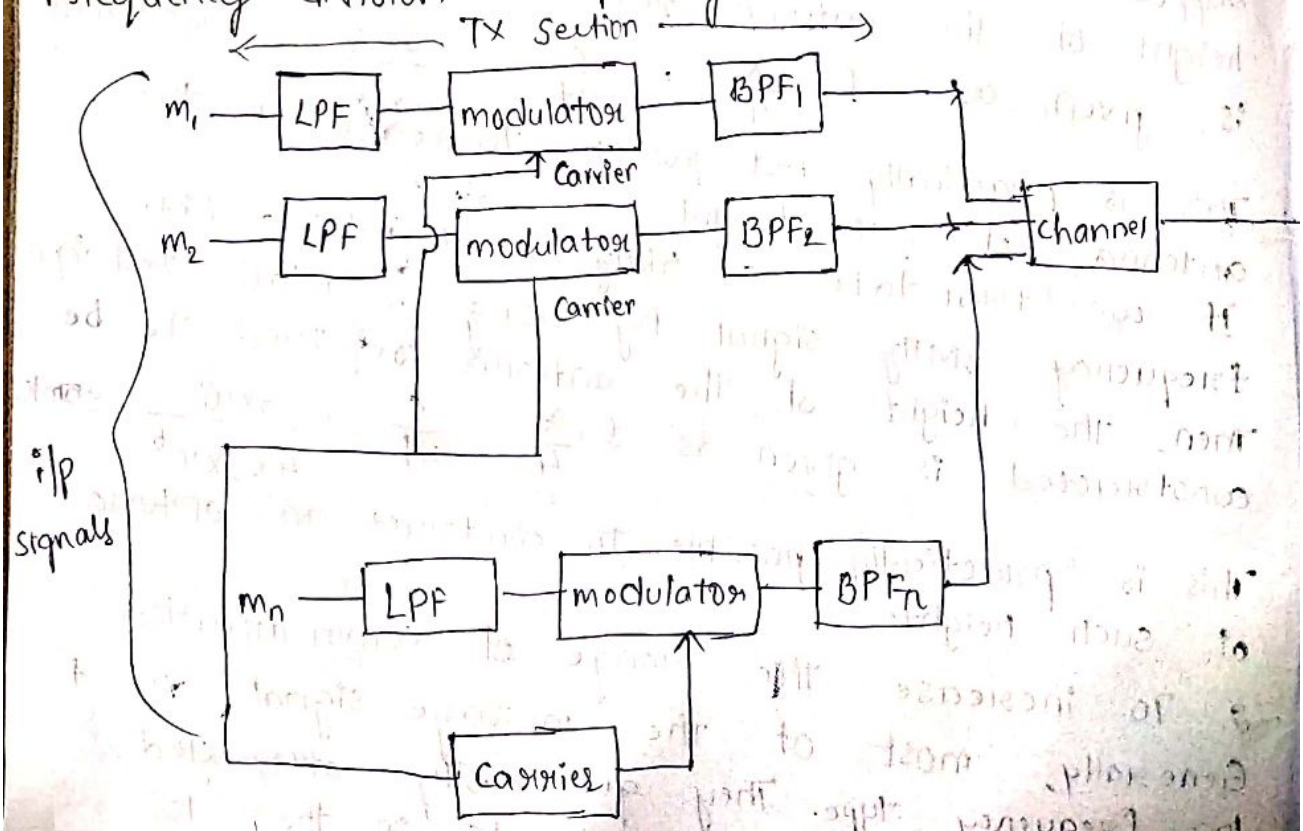




4. Reduction of noise.

Noise is the major draw back in any communication system. Although, noise cannot be eliminated completely, using modulation we can reduce the effect of noise

Frequency division Multiplexing:



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$m(t) = 2\cos 5000t$ $\quad \omega_m = 5000$

$c(t) = 5\cos 20000t$ $\quad \omega_c = 20000$

$m_a = \frac{2}{5} = 0.4$ $\quad 2\pi f_m = 5000$

$f_m = 795.77$

$f_{USB} = f_c + f_m$ $\quad 2\pi f_c = 20000$

$f_{USB} = 3978.86$ $\quad f_c = 3183.09$

$f_{LSB} = f_c - f_m = 2387.32$

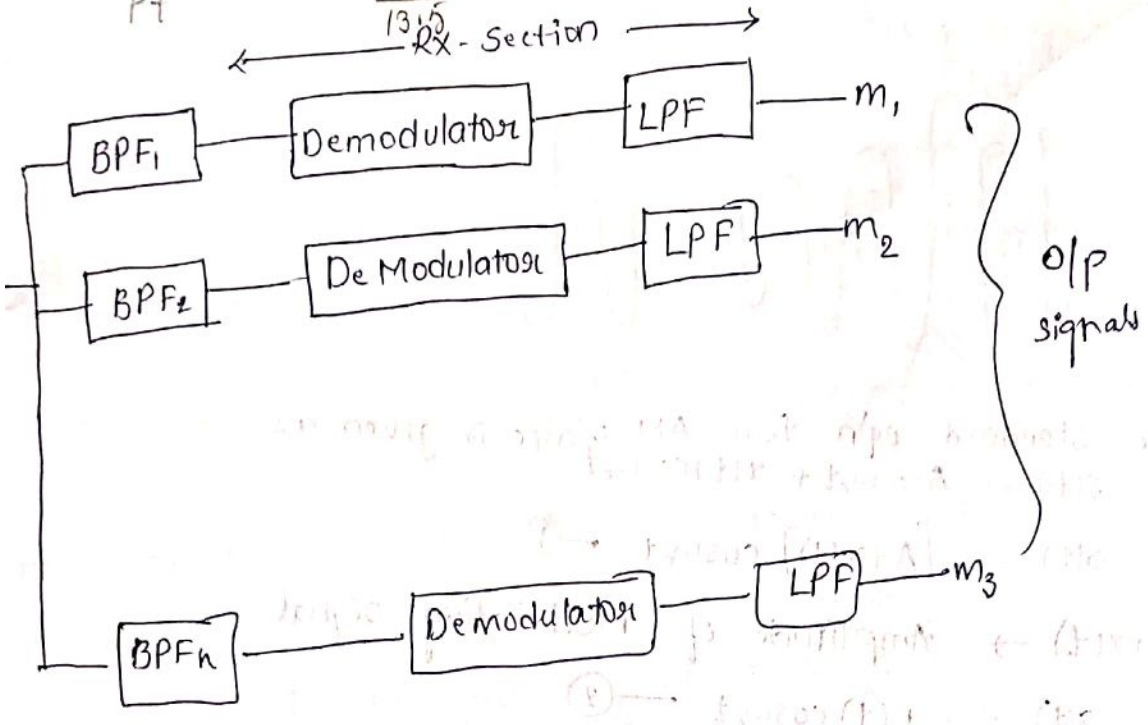
$BW = 2f_m = 1591.54$

$\frac{P_s}{P_t} = ?$ $\quad P_t = P_c\left[1 + \frac{m_a^2}{2}\right]$ $\quad P_t = P_c + P_s$

$\frac{P_t - P_c}{P_t}$ $\quad P_t = \frac{25}{2}\left[1 + \frac{(0.4)^2}{2}\right]$

$P_t = 13.5$

$1 - \frac{P_c}{P_t} = 1 - \frac{12.5}{13.5} = 0.074$



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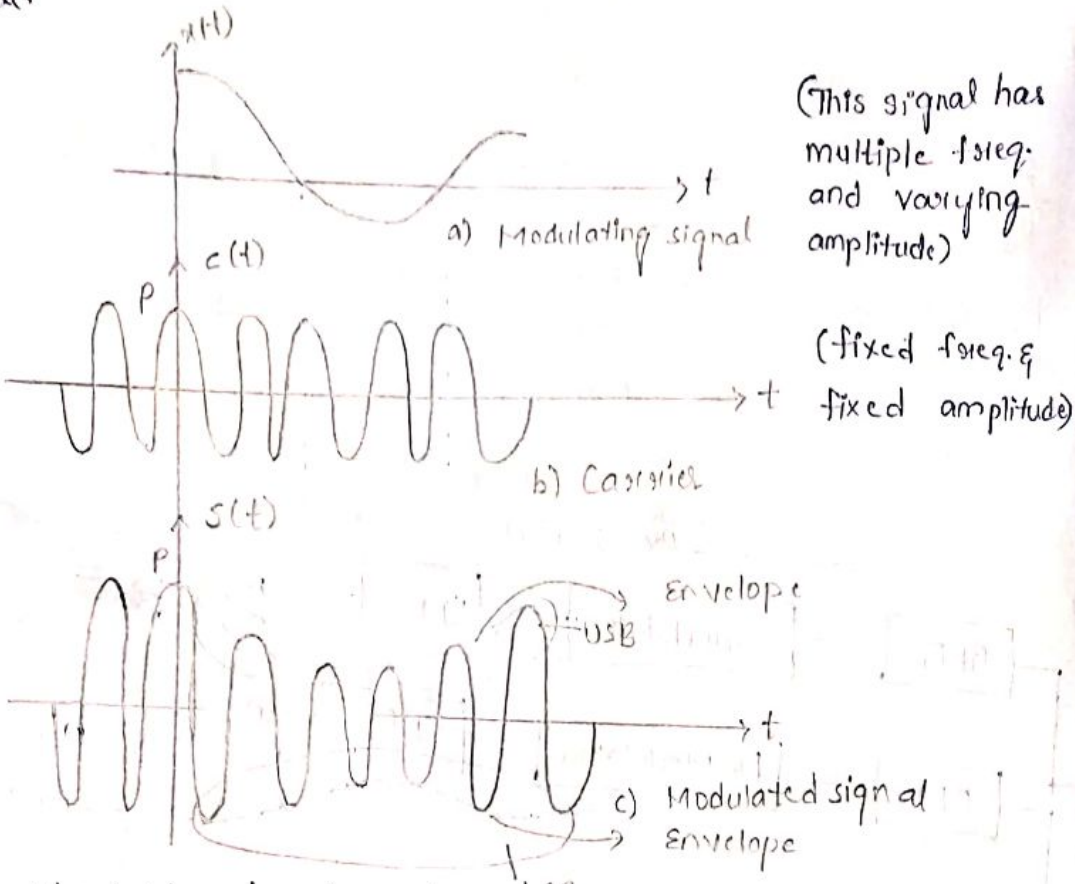
Amplitude Modulation (Time domain Analysis) :- (Multi-tone AM)

It is a process in which the amplitude of carrier signal is made proportional to the instantaneous amplitudes of message signal/modulating signal.

→ Let $x(t)$ be the i/p signal (or) modulating signal to be transmitted.

Let us consider a high frequency carrier signal $c(t) = A\cos\omega_c t$ where A - max. amplitude of carrier signal and ω_c represents angular frequency of carrier signal.



The standard eq'n for AM wave is given as

→ $s(t) = A\cos\omega_c t + x(t)\cos\omega_c t$

$s(t) = [A + x(t)]\cos\omega_c t$ —①

$A + x(t)$ → Amplitude of modulating signal

$s(t) = E(t)\cos\omega_c t$ —②

where $E(t)$ is envelope of $x(t)$.

According to AM, the amplitude of carrier signal is made proportional to " " msg "

as shown in fig (c).

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of 1 & eq 2 represents the time domain behaviour of AM wave.

Frequency domain Analysis of AM wave:

If $x(t)$ is the i/p signal (or) modulating signal and $c(t) = A\cos\omega_c t$ is a high frequency carrier signal then the standard equation for AM wave is given as

$$s(t) = A\cos\omega_c t + x(t)\cos\omega_c t \quad \text{—(1)}$$

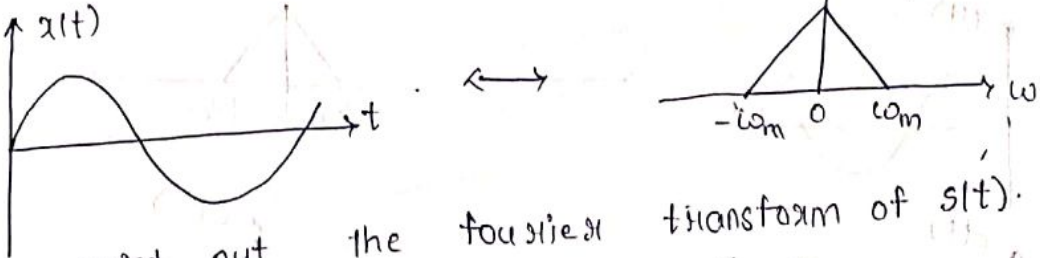
This eq represents the time domain behaviour of AM wave.

If we want to know the frequency representation (or) the frequencies present in AM wave, we need to find out the frequency spectrum (or) frequency domain analysis of FM wave. For that purpose, we need to find out fourier transform of $s(t)$.

Let $x(\omega)$ is a fourier transform of $x(t)$ and $c(\omega)$ is the fourier transform of $c(t)$ and $s(\omega)$ is the FT of $s(t)$ respectively.

Let the modulating signal $x(t)$ be band limited to the interval $-\omega_m < \omega < \omega_m$. This indicates that modulating signal doesnot have any frequency component outside the interval $(-\omega_m, \omega_m)$.

The signal $x(t)$ and its fourier transform is as shown in the figure below:



Now, point out the fourier transform of $s(t)$.

$$FT[s(t)] = FT[A\cos\omega_c t + x(t)\cos\omega_c t] \quad \text{—(2)}$$

$$= FT[A\cos\omega_c t] + FT[x(t)\cos\omega_c t]$$

$$= FT\left[A\left(\frac{e^{j\omega_c t} + e^{-j\omega_c t}}{2}\right)\right] + FT[x(t)\cos\omega_c t]$$

Consider, $FT[A\cos\omega_c t] = \frac{A}{2} FT\left[e^{j\omega_c t} + e^{-j\omega_c t}\right]$

$$= \frac{A}{2}\left[2\pi\delta(\omega - \omega_c) + 2\pi\delta(\omega + \omega_c)\right]$$

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$FT[A\cos\omega_c t] = A\pi[\delta(\omega-\omega_c)+\delta(\omega+\omega_c)]$ — ③

Consider $FT[x(t)\cos\omega_c t] = FT\left[x(t)\left(\frac{e^{j\omega_c t}+e^{-j\omega_c t}}{2}\right)\right]$

$= \frac{1}{2}\{FT[x(t)e^{j\omega_c t}] + FT[x(t)e^{-j\omega_c t}]\}$ — ④

From the frequency shifting theorem of fourier transform, we know that

$x(t) \longleftrightarrow X(\omega)$

$x(t)e^{j\omega_c t} \longleftrightarrow X(\omega-\omega_c)$

$x(t)e^{-j\omega_c t} \longleftrightarrow X(\omega+\omega_c)$

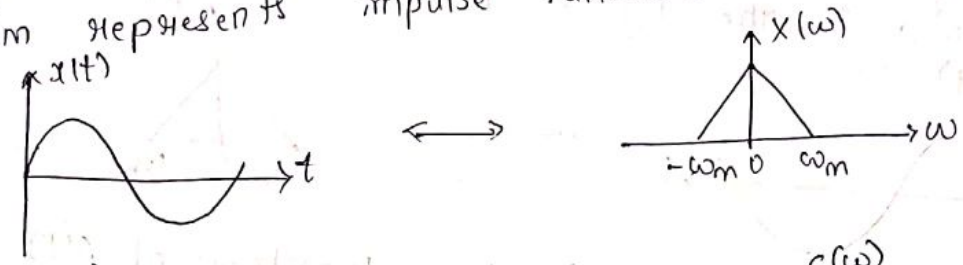
eq ④ $\Rightarrow$ $FT[x(t)\cos\omega_c t] = \frac{1}{2}[X(\omega-\omega_c)+X(\omega+\omega_c)]$ — ⑤

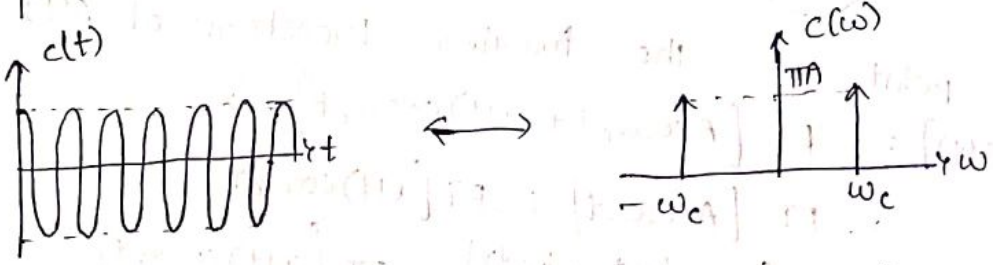
From eq's 2, 3, 5 we can write

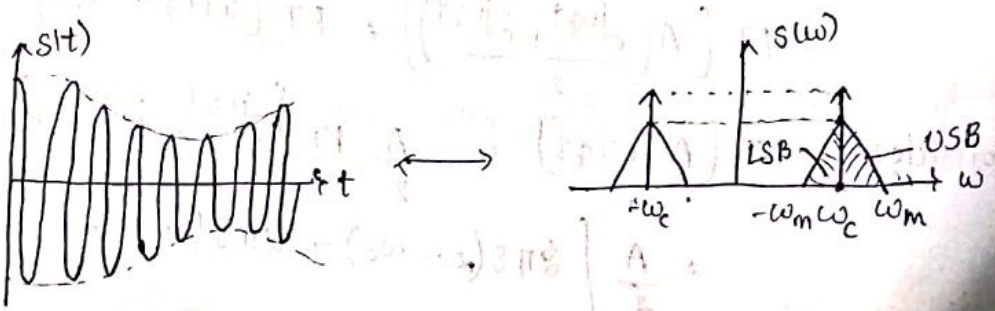
$$S(\omega) = A\pi[\delta(\omega-\omega_c)+\delta(\omega+\omega_c)] + \frac{1}{2}[X(\omega-\omega_c)+X(\omega+\omega_c)]$$

The above eq. represents the frequency domain of AM wave

It represents 2 components. The first component represents the spectrum of original base band signal shifted in positive direction as well as negative direction by an amount of ω_c. The 2nd term represents impulse functions.







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The band frequencies which lies above the carrier signal frequency is called upper side band else lower side band.

From the fig. band width modulated signal is

band width = $\omega_c + \omega_m - (\omega_c - \omega_m)$

$BW = 2\omega_m$ twice of

∴ It is represented as the maximum frequency of modulating signal.

Modulation Index (Amplitude Sensitivity):

Modulation Index is basically the ratio by which the modulated signal varies from an unmodulated carrier signal (or)

Modulation Index is simply the ratio of maximum amplitude of modulating signal and the maximum amplitude of carrier signal. It is denoted by 'ma'

It is given by $\boxed{m_a = \frac{|x(t)|_{max}}{A}}$

→ It can also be expressed in terms of percentage called percentage of modulation.

$m_a \times 100 \rightarrow \frac{|x(t)|_{max}}{A} \times 100$

→ It is also known as depth of modulation (or) Modulation factor.

* $m_a \leq 1$, if we want to completely recover our msg signal, from the envelope of AM wave.

* $m_a > 1$, Envelope distortion occurs.

* In order to get distorted o/p.

$m_a < 1$ (or) $x(t)_{max} < A_c$ (or) $m.I < 100\%$.

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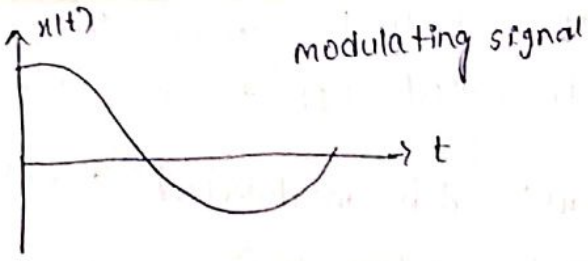
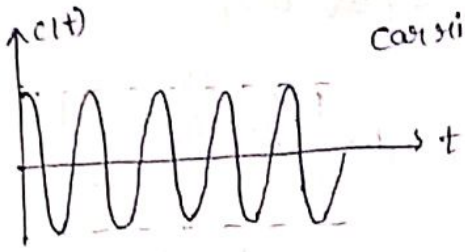
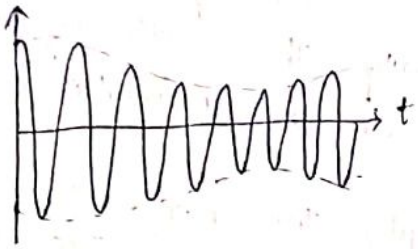


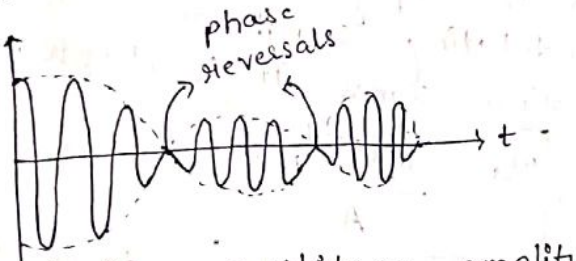
modulating signal



carrier sgl.



AM wave for ma<1 (under modulation)



AM wave for ma > 1 over modulation

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Power Content in a multitone amplitude Modulation

Multitone modulation is a type of modulation in which the modulating signal consists of multiple frequencies in it

Let us consider a carrier signal $A\cos\omega_c t$ is modulated by a multitone modulating signal which is given as $x(t) = V_1\cos\omega_1 t + V_2\cos\omega_2 t + V_3\cos\omega_3 t$ — (1)

we know that the standard equation for an AM wave is represented by $s(t)$.

$$s(t) = A\cos\omega_c t + x(t)\cos\omega_c t \quad \text{— (2)}$$

Sub. eq (1) in eq (2)

$$s(t) = A\cos\omega_c t + (V_1\cos\omega_1 t + V_2\cos\omega_2 t + V_3\cos\omega_3 t)\cos\omega_c t$$

$$= A\cos\omega_c t\left[1 + \frac{V_1}{A}\cos\omega_1 t + \frac{V_2}{A}\cos\omega_2 t + \frac{V_3}{A}\cos\omega_3 t\right]$$

wkt, The maximum amplitude of modulating signal / maximum amplitude of carrier signal

$$= m_a$$

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Here $\frac{V_1}{A} = m_1$; $\frac{V_2}{A} = m_2$; $\frac{V_3}{A} = m_3$

$\therefore s(t) = A\cos\omega_c t \left[1 + m_1\cos\omega_1 t + m_2\cos\omega_2 t + m_3\cos\omega_3 t\right]$

$s(t) = A\cos\omega_c t + mA\cos\omega_c t\cos\omega_1 t + m_2 A\cos\omega_2 t\cos\omega_c t +$

$m_3 A\cos\omega_3 t\cos\omega_c t$ —(3)

Let us calculate the power content in an AM wave

The power content in an AM wave can be calculated as $P_t = P_c + P_s$ —(4) where as P_t = total power

P_c : carrier power

P_s : sidebands power

Let us calculate the carrier power.

The power carried out by carrier signal is nothing but the, mean square value of $A\cos\omega_c t$

$$P_c = \left[\overline{A^2\cos^2\omega_c t}\right]^{\frac{1}{2}}$$

$$= \frac{1}{2\pi}\int_0^{2\pi} A^2\cos^2\omega_c t\, dt$$

$$= \frac{A^2}{2\pi}\int_0^{2\pi}\left(\frac{1+\cos 2\omega_c t}{2}\right)dt$$

$$= \frac{A^2}{4\pi}\left(t + \frac{\sin 2\omega_c t}{2\omega_c}\right)_0^{2\pi}$$

$$= \frac{A^2}{4\pi}(2\pi) = \frac{A^2}{2}$$

$$\therefore P_c = \frac{A^2}{2} \quad —(5)$$

Generally, in AM transmission, a band pass filter (or) a tuned ckt with cut off frequency ω_c, is used to reject higher frequency component i.e; the 2nd integral term in above is zero.

Now, let us calculate the side band power.

The power carried out by side bands can be calculated by using the equation.

$$P_s = \frac{1}{2}\left[\overline{x(t)}\right]^2$$

$$= \frac{1}{2}\left[\overline{(V_1\cos\omega_1 t) + (V_2\cos\omega_2 t) + (V_3\cos\omega_3 t)}\right]^2$$

$$= \frac{1}{2}\left[\overline{(m_1 A\cos\omega_1 t)^2} + \overline{(m_2 A\cos\omega_2 t)^2} + \overline{(m_3 A\cos\omega_3 t)^2}\right]$$

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$$P_s(t) = \frac{1}{2}\left[\frac{m_1^2A^2}{2} + \frac{(m_2A)^2}{2} + \frac{(m_3A)^2}{2}\right]$$

$$P_s(t) = \frac{A^2}{4}\left[m_1^2 + m_2^2 + m_3^2\right] \quad \text{— (6)}$$

Sub. eq 5, 6 in eq (4)

$$P_t = P_c + P_s$$

$$= \frac{A^2}{2} + \frac{A^2}{4}(m_1^2 + m_2^2 + m_3^2)$$

$$P_t = \frac{A^2}{2}\left\{1 + \frac{1}{2}(m_1^2 + m_2^2 + m_3^2)\right\}$$

$$\boxed{P_t = P_c\left\{1 + \frac{m_1^2 + m_2^2 + m_3^2}{2}\right\}}$$

The above expression can be extended upto 'n' frequency components

$$P_t = P_c\left\{1 + \frac{m_1^2 + m_2^2 + m_3^2 + \cdots + m_n^2}{2}\right\}$$

Total modulation Index (or) net modulation index :-

We know that, the total power transmitted (or) carried out by an multitone AM wave is

$$P_t = P_c\left[1 + \frac{m_1^2 + m_2^2 + m_3^2 + \cdots + m_n^2}{2}\right]$$

The above equation can also be expressed as

$P_t = P_c\left[1 + \frac{m_t^2}{2}\right]$, where $m_t^2 = m_1^2 + m_2^2 + \cdots + m_n^2$ (or)

$m_t = \sqrt{m_1^2 + m_2^2 + m_3^2 + \cdots + m_n^2}$.

m_t = total modulation index (or) net modulation index

Single tone Amplitude Modulation :- (Time domain)

Single tone amplitude modulation is a type of modulation in which the modulating signal is a fixed frequency signal (single frequency).

Let us consider a carrier signal $c(t) = A\cos\omega_c t$ is modulated by a single frequency modulating signal $x(t)$ which is

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$x(t) = V_m \cos\omega_m t$ — ①

We know, the standard equation for an AM wave is

$s(t) = A\cos\omega_c t + x(t)\cos\omega_c t$ — ②

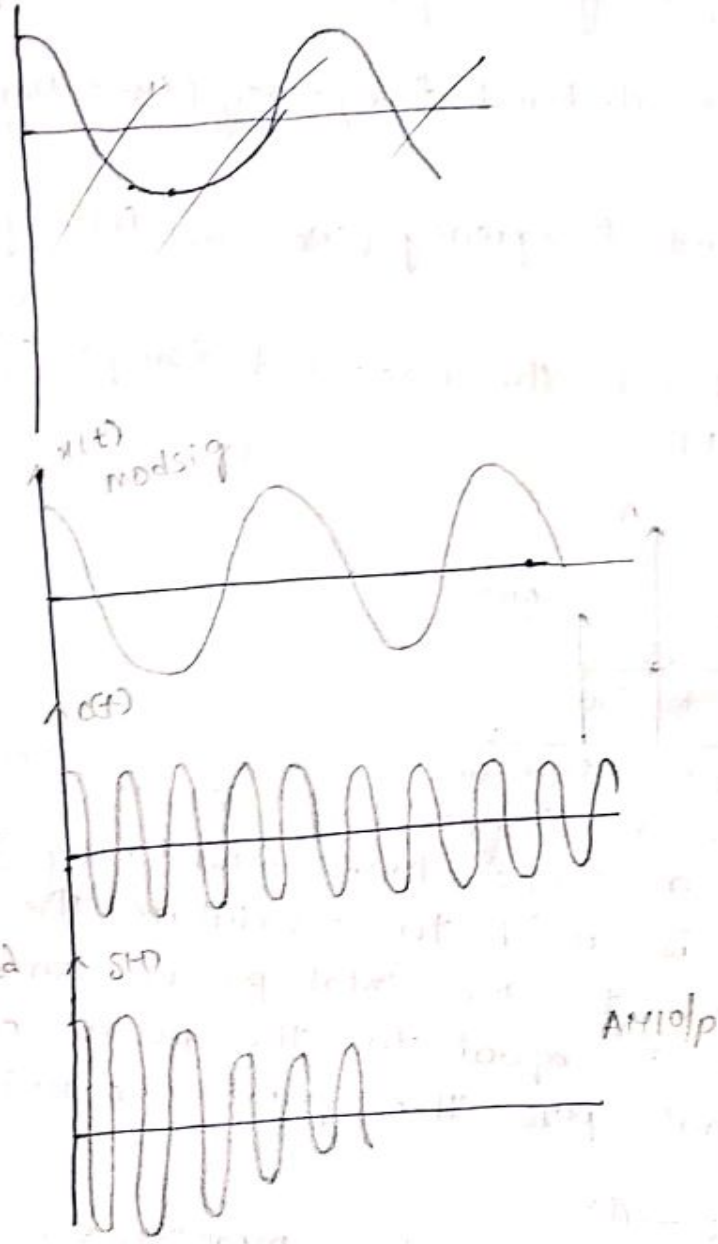
Substitute eq ① in eq ②

$s(t) = A\cos\omega_c t + V_m \cos\omega_m t \cos\omega_c t$

$= A\cos\omega_c t \left[1 + \frac{V_m}{A}\cos\omega_m t\right]$

here $\frac{V_m}{A} = m_a$

$\therefore \boxed{s(t) = A\cos\omega_c t\,[1 + m_a \cos\omega_m t]}$



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Frequency domain Representation

For a single tone AM,

WKT $s(t) = A\cos\omega_c t\left[1 + m_a\cos\omega_m t\right]$

$= A\cos\omega_c t + Ama\cos\omega_c t\cos\omega_m t$

$= A\cos\omega_c t + \frac{Ama}{2}\left(2\cos\omega_c t\cos\omega_m t\right)$

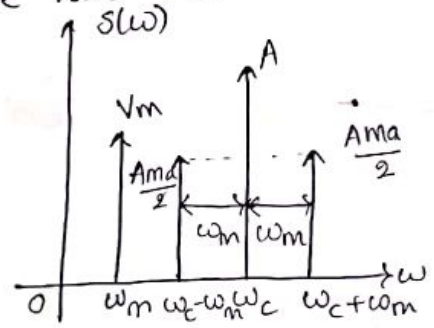
$s(t) = A\cos\omega_c t + \frac{Ama}{2}\left[\cos(\omega_c t + \omega_m t) + \cos(\omega_c t - \omega_m t)\right]$

① ② ③

The above eq. reveals 3 frequency components.

1. Carrier frequency component - ω_c having an amplitude of 'A'
2. Represents upper side band frequency $(\omega_c + \omega_m)$ having an amplitude $\frac{Ama}{2}$
3. Lower side band frequency $(\omega_c - \omega_m)$ having an amplitude $\frac{Ama}{2}$

The fig. below shows the onesided frequency spectrum of single tone AM



Power Content in a Single tone AM :-

Let us consider a single tone modulating signal $x(t) = V_m\cos\omega_m t$ is used to modulate the carrier signal $c(t) = A\cos\omega_c t$. The total power carried out by an AM wave is - equal to the power carried out by carrier signal plus the power carried out by side bands.

$P_t = P_c + P_s$ — ①

Here P_c is nothing but the meansquare value of $A\cos\omega_c t$

$P_c = \left[\overline{A\cos\omega_c t}\right]^2$

$P_c = \frac{A^2}{2}$ — ②

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Similarly, the side band power P_S is given by

$$P_S = \frac{1}{2}\overline{x(t)}$$

$$= \frac{1}{2}\overline{[V_m \cos\omega_m t]^2}$$

$$= \frac{1}{2}\frac{V_m^2}{2}$$

$$P_S = \frac{V_m^2}{4} \quad \text{—(3)}$$

∴ The total power transmitted in AM wave is

$$P_t = \frac{A^2}{2} + \frac{V_m^2}{4}$$

$$P_t = \frac{A^2}{2}\left[1 + \frac{V_m^2}{A^2}\cdot\frac{1}{2}\right]$$

$$\boxed{P_t = P_c\left[1 + \frac{1}{2}m_a^2\right]}$$

Current Calculation in a Single tone AM wave :-

In AM it is generally more convient to measure the AM transmitter current than the power. In this case, the modulation index may be calculated from the values of unmodulated and modulated currents in the AM transmitter.

WKT, the total power transmitted in a singletone AM wave is

$$P_t = P_c\left(1 + \frac{m_a^2}{2}\right) \quad \text{—(1)}$$

Let us assume I_t is the total transmitted current (or) modulated current and I_c is the carrier current (or) unmodulated current.

From eq (1)

$$\frac{P_t}{P_c} = 1 + \frac{m_a^2}{2}$$

$$\frac{I_t^2 \cdot R}{I_c^2 \cdot R} = 1 + \frac{m_a^2}{2}$$

$$\therefore \left(\frac{I_t}{I_c}\right)^2 = 1 + \frac{m_a^2}{2}$$

$$\frac{I_t}{I_c} = \sqrt{1 + \frac{m_a^2}{2}}$$

$$I_t = I_c\sqrt{1 + \frac{m_a^2}{2}}$$

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1. Derive the expression for modulation index in terms of P_t and P_c.
Derive the expression for modulation index in terms of I_t and I_c.

2. A modulating signal $10\sin(2\pi\times10^3t)$ is used to modulate a carrier signal $20\sin(2\pi\times10^4t)$. Determine the modulation index, % of ma, frequencies of side band components and their amplitudes. what will the bandwidth of modulated signal.

3. A 400 watts carrier is modulated to a depth of 75 %. Find the total power in the amplitude modulated wave

4. An AM broadcast radio transter radiates 10k watts of power if % modulation % is 60. Calculate the carrier power

1. WKT $P_t = P_c\left[1+\frac{m_a^2}{2}\right]$; $I_t = I_c\sqrt{\left(1+\frac{m_a^2}{2}\right)}$

$$\frac{P_t}{P_c} = 1+\frac{m_a^2}{2} \qquad \frac{I_t}{I_c} = \sqrt{\frac{m_a^2}{2}+1}$$

$$2\left(\frac{P_t}{P_c}-1\right) = m_a^2 \qquad \left(\frac{I_t}{I_c}\right)^2-1 = \frac{m_a^2}{2} \quad ; \quad 2\left(\frac{I_t}{I_c}-1\right)$$

$$m_a = \sqrt{2\left(\frac{P_t-P_c}{P_c}\right)} \qquad m_a = \sqrt{2\left(\frac{I_t-I_c}{I_c}\right)}$$

$$m_a = \sqrt{2\left(\frac{I_t}{I_c}\right)^2-2}$$

2 Given,

$x(t) = 10\sin(2\pi\times10^3t)$; $c(t) = 20\sin(2\pi\times10^4)t$

$$m_a = \frac{|x(t)|_{max}}{|c(t)|_{max}} = \frac{10}{20} = 0.5$$

% m_a = 50 %

$f_L = 10^3$ $f_H = 10^4$

BW = $f_H - f_L = 10^4 - 10^3 = 10$

Upper Side band frequency = $\omega_c+\omega_m = f_c+f_m$

$= 10^4+10^3$

Amplitude = $\frac{Am_a^2}{2} = \frac{20\times(0.5)^2}{2} = 1.25$ V = 11000

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Lower side band frequency = $\omega_c - \omega_m = 10^4 - 10^3 = 9000$ Hz

Amplitude = $\frac{Ama}{2} = \frac{20 \times 0.5}{2} = 5$

Band width = $2f_m = 2 \times 10^3 = 2000$ Hz.

3) Given,

$P_c = 400\omega$

$m_a = 75\% = 0.75$

$P_t = ?$

$P_t = P_c \left[1 + \frac{m_a^2}{2}\right]$

$P_t = 400 \left[1 + \frac{(0.75)^2}{2}\right]$

$P_t = 512.5\omega$

4) $m_a = 60\% = 0.6$

$P_c = ?$

$P_t = 10000$

$P_t = P_c \left[1 + \frac{m_a^2}{2}\right]$

$10000 = P_c \left[1 + \frac{(0.6)^2}{2}\right]$

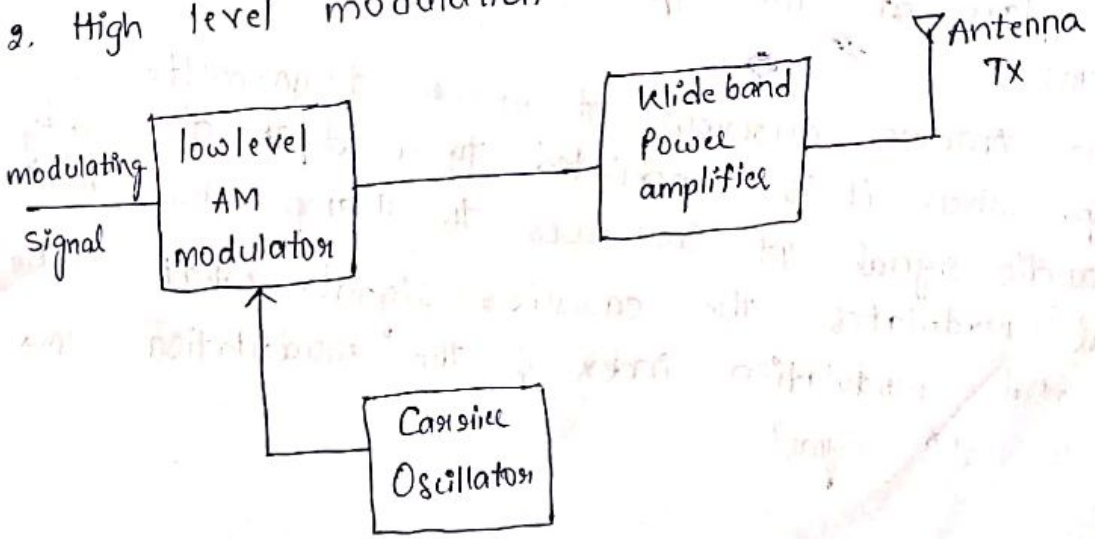
$P_c = 8474.5\omega = 8.47$ kw

Generation of Amplitude Modulation:

The circuit which is used to generate AM wave is called as AM generator.

Generally, Amplitude modulation can be achieved by using two types of techniques:

1. Low level modulation
2. High level modulation



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Carrier Oscillator is used to generate Carrier signal.

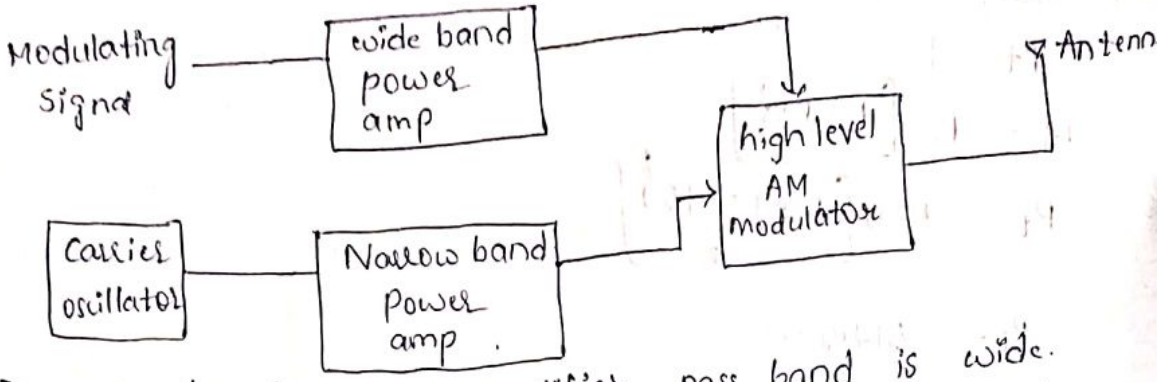
High level Modulation :-

Some of the examples of low level modulation :-

1. Square law dibde modulation
2. Switching Modulation

$\omega_c = 10^7$
$\omega_m = 10^3$

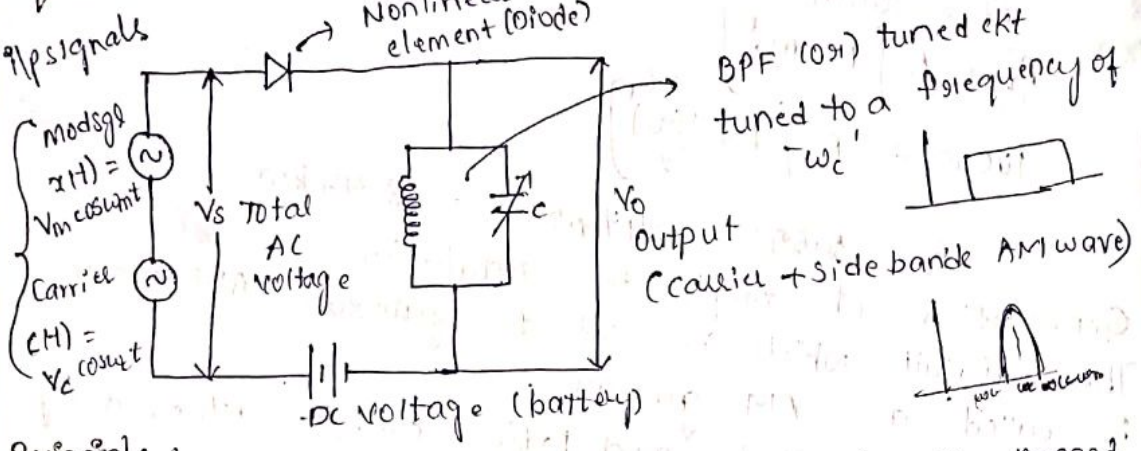
High level Modulation :-



In wide band power amplifier pass band is wide.

In narrow band power amplifier pass band is narrow.

Square law diode Modulation :-



Principle :-

when two signals of different frequencies are passed through a non linear element, then AM modulation takes place at the o/p.

Problems :-

5) The Antenna current of an AM transmitter is 10 Amp. when it is modulated to a depth of 30% by an audio signal. It increases to 11 amp when another signal modulates the carrier signal. what will be the total modulation index & the modulation index due to 2nd signal?

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$I_{t_1} = 10A$

$M_1 = m_a = 0.3$; $m_t = ?$ when $I_{t_2} = 11A$

$M_2 = ?$

wkt $I_t = I_c \sqrt{1 + \frac{m_t^2}{2}}$

$10 = I_c \sqrt{1 + \frac{(0.3)^2}{2}}$

$10 = I_c (1.022)$

$I_c = 9.784\ A$

$I_{t_2} = I_c \sqrt{1 + \frac{m_t^2}{2}}$

$11 = 9.784 \sqrt{1 + \frac{m_t^2}{2}}$

$1 + \frac{m_t^2}{2} = 1.263$

$\frac{m_t^2}{2} = 0.263$

$m_t^2 = 0.527$

$m_t = 0.725$

wkt $m_t^2 = m_1^2 + m_2^2$

$(0.725)^2 = (0.3)^2 + m_2^2$

$m_2^2 = 0.435$

$m_2 = 0.65 = 65\%$

6) The antenna current of an AM transmitter is modulated to a depth of 40% by an audio wave is 11 amp. It increases to 12 amp as a result of simultaneous modulation by another audio wave. what is the modulation index due to the 2nd wave

$I_{t_1} = 11$ amp ; $I_{t_2} = 12A$

$m_1 = 0.4$; $m_2 = ?$

$I_{t_1} = I_c \sqrt{1 + 0.08}$

$11 = I_c (1.039)$

$I_c = 10.58$

$I_{t_2} = I_c \sqrt{1 + \frac{m_t^2}{2}}$

$\frac{12}{10.58} = \sqrt{1 + \frac{m_t^2}{2}}$

$1.134 = \sqrt{1 + \frac{m_t^2}{2}}$

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$$\frac{m_f^2}{2} = 0.286$$

$$m_f = 0.756$$

wkt $m_f^2 = m_1^2 + m_2^2$

$$(0.756)^2 = 0.16 + m_2^2$$

$$0.411 = m_2^2$$

$$m_2 = 0.641 = 64\%$$

7) A carrier wave is represented by the expression $V_c(t) = 10\sin\omega t$ then draw the waveform of an AM wave for $m = 0.5$.

Given that, $V_c(t) = 10\sin\omega t$

$M = 0.5$

$A_c = 10V$

Inorder to draw AM output we need to find out E_{max} & E_{min}.

wkt the modulation index $m_a = \frac{A_m}{A_c}$

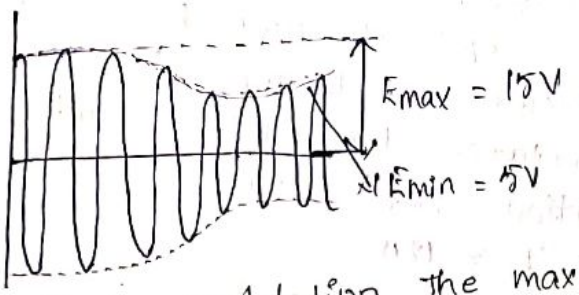
$$0.5 = \frac{A_m}{10}$$

$A_m = 5V$

$E_{max} = A_c + A_m$

$= 5 + 10 = 15V$

$E_{min} = A_c - A_m = 10 - 5 = 5V$



8) P.T in amplitude modulation the maximum avg. power transmitted by an antenna is 1.5 times the carrier power?

Given that,

$$P_t = P_c\sqrt{1 + \frac{m_a^2}{2}} \quad \text{—①}$$

$m_a = 1$ ∴ The maximum value, without introducing any distortion in AM o/p

$m_a > 1$ = o/p gets distorted.

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substitute $M_a = 1$ in above equation.

$$P_t = P_c\sqrt{1+\frac{1}{2}}$$

$$P_t = P_c(1.5)$$

Square law diode Modulator:

The fig shows the ckt diagram of square law diode modulation in which modulating signal $x(t)$ and carrier signal $c(t)$ are applied across the diode.

Let us consider $x(t) = V_m \cos\omega_m t$ and $c(t) = V_c \cos\omega_c t$ where ω_m is modulating frequency and ω_c is carrier frequency.

From the fig we can observe that the total AC voltage which is applied across a non linear element (diode) is V_s.

$$V_s = V_m \cos\omega_m t + V_c \cos\omega_c t \quad \text{--- (1)}$$

The non linear relation ship b/w voltage and current for a diode can be expressed as

$$i_0 = a + bV_s + cV_s^2 \quad \text{--- (2)}$$

i = o/p current

V_s = total i/p voltage applied across the diode

Substitute eq (1) in eq (2)

$$i = a + b\left[V_m\cos\omega_m t + V_c\cos\omega_c t\right] + c\left[V_m\cos\omega_m t + V_c\cos\omega_c t\right]^2$$

$$i = a + b\left[V_m\cos\omega_m t + V_c\cos\omega_c t\right] + c\left[V_m^2\cos^2\omega_m t + V_c^2\cos^2\omega_c t + 2V_mV_c\cos\omega_m t\cos\omega_c t\right]$$

$$i = a + b\left[V_m\cos\omega_m t + V_c\cos\omega_c t\right] + c\left[V_m^2\left(\frac{1+\cos 2\omega_m t}{2}\right) + V_c^2\left(\frac{1+\cos 2\omega_c t}{2}\right) + 2V_mV_c\cos\omega_m t\cos\omega_c t\right]$$

$$i = a + bV_m\cos\omega_m t + bV_c\cos\omega_c t + \frac{cV_m^2}{2} + \frac{cV_m^2\cos 2\omega_m t}{2} + \frac{cV_c^2}{2} + \frac{cV_c^2\cos 2\omega_c t}{2} + c\left[V_mV_c\cos(\omega_m+\omega_c)t + \cos(\omega_m-\omega_c)t\right]$$

$$i = a + bV_m\cos\omega_m t + bV_c\cos\omega_c t + \frac{cV_m^2}{2} + \frac{cV_m^2\cos 2\omega_m t}{2} + \frac{cV_c^2}{2} + \frac{cV_c^2\cos 2\omega_c t}{2} + cV_mV_c\cos(\omega_m+\omega_c)t + cV_mV_c\cos(\omega_m-\omega_c)t$$

$$i = \underbrace{a + \frac{cV_m^2}{2} + \frac{cV_c^2}{2}}_{(1)} + \underbrace{bV_m\cos\omega_m t}_{(2)} + \underbrace{bV_c\cos\omega_c t}_{(3)} + \underbrace{\frac{cV_m^2\cos 2\omega_m t}{2}}_{(4)} + \underbrace{\frac{cV_c^2\cos 2\omega_c t}{2}}_{(4)} + \underbrace{cV_mV_c\left\{\cos(\omega_m+\omega_c)t + \cos(\omega_m-\omega_c)t\right\}}_{(5)}$$

The above equation reveals 5 frequency components. They are

1. DC components of the signal
2. modulating signal frequency ω_m
3. Carrier signal frequency ω_c ✓
4. harmonics of modulating signal and carrier signal having frequencies $2\omega_m$ and $2\omega_c$.
5. represents upper side band and lower side band frequencies $(\omega_c + \omega_m)$, $(\omega_c - \omega_m)$ ✓

Now, all these frequency components are applied to a tuned circuit which is set to a centre frequency of ω_c. From all these frequency components only the carrier frequency and the sideband frequencies are allowed by the tuned circuit and all other remaining frequency components are rejected by the tuned circuit.

Therefore, the required expression for the o/p current is $i = bV_c\cos\omega_c t + cV_mV_c\left[\cos(\omega_m+\omega_c)t + \cos(\omega_m-\omega_c)t\right]$.

$$i = bV_c\cos\omega_c t + c2V_mV_c\cos\omega_m t\cos\omega_c t$$

$$i = bV_c\cos\omega_c t\left[1 + \frac{c2V_m}{b}\cos\omega_m t\right]$$

$$i = bV_c\cos\omega_c t\left[1 + m_a\cos\omega_m t\right]$$

where $m_a = \frac{2cV_m}{b}$ represents modulation index.

The above expression represents carrier frequency and two side band frequencies which is nothing but amplitude modulated wave. The ckt acts as a AM generator.

AM detection (or) Envelope detection (or) AM demodulation:-

The figure shows the circuit diagram of envelope detector.

We know that, the envelope of AM wave follows the amplitude variations of the modulating signal. This circuit tries to detect the envelope of the AM wave Thats why it is called as Envelope Detector

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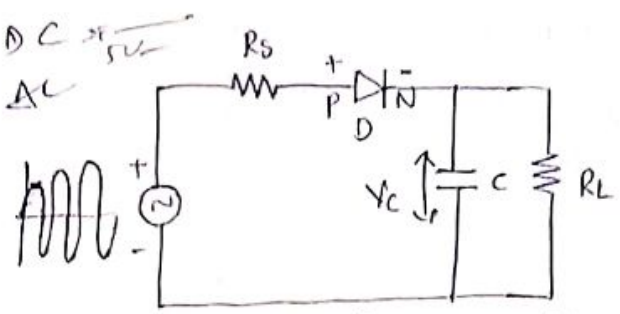

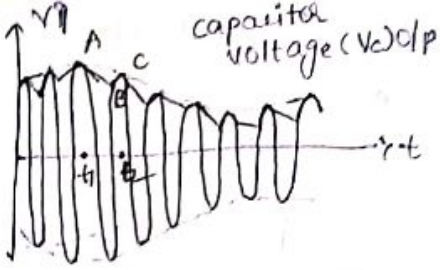

Envelope detection is a very simple and inexpensive as it contains diode and a few resistors, capacitor

Circuit operation :-

For positive half cycle of AM wave.

Diode is ON - conducting - capacitor charge through R_s.

For negative half cycle of AM wave

Diode is OFF - stops conducting - capacitor discharges through R_L.

* $R_s C << \frac{1}{f_c}$

$R_L C >> \frac{1}{f_c}$

Efficiency of amplitude modulation :-

The efficiency of a AM wave is the ratio of power carried out by the side bands to the total power carried out by an AM wave

$$\eta = \frac{\text{Power carried out by side bands}}{\text{total power carried out by an AM wave}}$$

$$= \frac{\frac{V_m^2}{4}}{P_c\left[1 + \frac{m_a^2}{2}\right]}$$

wkt $m_a = \frac{V_m}{A_c}$

$V_m = m_a A_c$

$P_c = \frac{A_c^2}{2}$

$$= \frac{\frac{m_a^2 A_c^2}{4\,2}}{\left(\frac{A_c^2}{2}\right)\left[1 + \frac{m_a^2}{2}\right]}$$

$$= \frac{\frac{m_a^2}{8}}{\frac{2 + m_a^2}{2}} = \frac{m_a^2}{m_a^2 + 2}$$

$$\eta = \frac{m_a^2}{m_a^2 + 2}$$

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For 100% modulation, for $m_a = 1$,

$$\eta = \frac{1}{1+2} = \frac{1}{3} = 0.33$$

$$\eta\% = 33.3\%$$

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